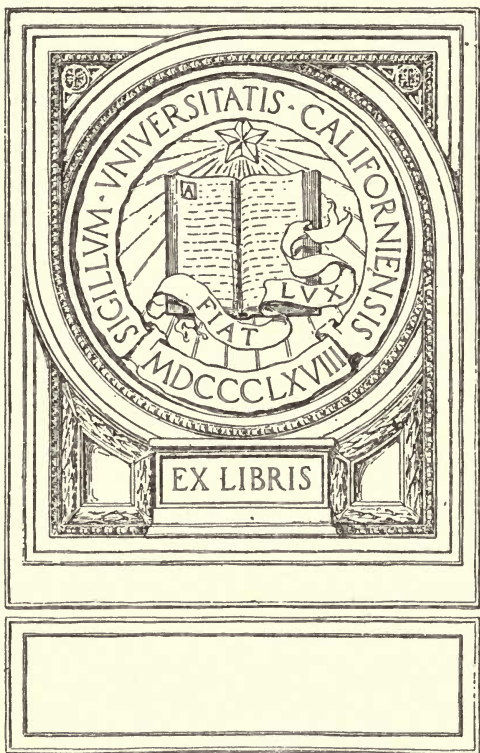


ELECTRIC
LIGHTING

GIFT OF

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ELECTRIC LIGHTING.

ELECTRIC LIGHTING

ELECTRIC LIGHTING

TRANSLATED FROM THE FRENCH OF

LE COMTE TH. DU MONCEL

BY

ROBERT ROUTLEDGE, B.Sc. (LOND.), F.C.S.

Author of

"DISCOVERIES AND INVENTIONS OF THE NINETEENTH CENTURY,"

"A POPULAR HISTORY OF SCIENCE," ETC.

WITH SEVENTY-SIX ILLUSTRATIONS

SECOND EDITION

LONDON

GEORGE ROUTLEDGE AND SONS

BROADWAY, LUDGATE HILL

NEW YORK: 9 LAFAYETTE PLACE

1883

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DISCOVERIES AND INVENTIONS
OF THE
NINETEENTH CENTURY.

BY ROBERT ROUTLEDGE, B.SC. (LOND.), F.C.S.

With 400 Illustrations, Portraits, &c.

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TRANSLATOR'S PREFACE.

THE book in the reader's hand is a translation of the second edition of the Comte du Moncel's "*L'Éclairage Électrique*," published at Paris, by the Messrs. Hachette, in 1880. Though the original work is one of a series intended for popular use, it leaves nothing to be desired on the score of scientific treatment. An able and thorough handling of the subject that occupies the present volume is, indeed, precisely what would be expected by those who are acquainted with the very eminent scientific position of the Comte du Moncel as an investigator and as an author. While the general reader will find in the following pages all that he can possibly require to know about electric lighting, and find it, too, laid before him in full and lucid explanations, divested of all perplexing technicalities, it is believed that the book may prove of more extended and important utility, by supplying serviceable guidance to the daily increasing number of persons who are called upon to consider how far this latest gift of science can be applied to their purposes. Such are more especially engineers, architects, managers of industrial and commercial establishments of all kinds, municipal officers, members of local boards, directors of railway and steamship companies, lessees of theatres, curators of museums, and of picture galleries, etc., besides other classes of persons too numerous to mention. A remarkable feature of the present work—because it is a merit by no means common, either in scientific or in popular books—is, that

from the first page to the last, the practical point of view is never for an instant abandoned.

No special knowledge of electrical science is needed for the intelligent perusal of this work; nevertheless, a reader altogether new to the subject would do well to acquire clear ideas of a few elementary facts. Almost any of the cheap manuals which now abound would suffice to convey all the information required; but it could not, perhaps, be attained more pleasantly and profitably than by a reference to Professor Tyndall's "Notes of a Course of Seven Lectures on Electrical Phenomena and Theories," which may be had for a few pence.

The present translation contains all the author's notes, references, and appendices. To these, two other appendices are now added by the translator. The first gives the English equivalents of the French weights, measures, etc., which, on account of their now almost universal employment for scientific purposes, it has been deemed expedient to retain in the text. The second is a brief notice of some forms of incandescent lamps, and of another recent invention, which have come into prominence since the publication of the original work. Several lamps of this kind may now be said to have proved completely successful in practice, and the forms described in the appendix are those which have attracted the largest share of public attention, as offering the simplest and most effective solution of nearly all the difficulties that have hitherto attended the application of electric lighting to domestic and certain other purposes.

The translator, having been unable to refer to some of the English and American newspapers, journals, and reports quoted by the author, has usually contented himself with a faithful rendering of the French version; but it is not, of course, to be expected that the *ipsissima verba* of the

originals will appear by this process of re-translation. The inverted commas, used to mark passages cited *verbatim*, have generally been suppressed in such cases.

With but two or three unimportant exceptions, the illustrations in this volume are identical with, or equivalent to, those of the original work. The translator and the publishers desire gratefully to acknowledge the kindness of Messrs. Blackie, in allowing the use of several cuts from their excellent edition of *Deschanel's Natural Philosophy*, namely, those which appear in this volume as Figs. 1, 2, 4, 5, 10, 11, 12, 13, 15, 18, 38, and 72. A like acknowledgment is also due to M. Werdermann for his permission to use the illustrations forming Figs. 37 and 57.

R. R.



CONTENTS.

PART I.—GENERAL CONSIDERATIONS.

	PAGE
HISTORICAL SKETCH ...	I
IMPORTANT DEFINITIONS ...	4
<i>Electric current</i> ...	4
<i>Electro-motive force</i> ...	5
<i>Tension of a current</i> ...	5
<i>Electrical potential</i> ...	6
<i>Electrical intensity</i> ...	6
<i>Electrical resistance</i> ...	7
<i>Electrical conductivity</i> ...	8
<i>Electrodes</i> ...	9
<i>Polarization</i> ...	9
Electric Units ...	10
WHAT THE ELECTRIC LIGHT IS ...	12
THE VOLTAIC ARC ...	16

PART II.—GENERATORS OF ELECTRIC LIGHT.

VOLTAIC GENERATORS ...	25
<i>Grove's and Bunsen's batteries</i> ...	25

	PAGE
<i>Voltaic constants</i>	29
<i>Grouping of elements for tension or for quantity</i> ...	30
<i>Conditions for maximum current</i>	32
<i>Derived circuits</i>	32
Mode of Propagation of Electricity	35
THERMO-ELECTRIC GENERATORS	38
<i>History</i>	38
<i>Clamond's piles</i>	39
MAGNETO-ELECTRIC GENERATORS	46
<i>Induced current</i>	46
History of the Question	46
THE DIFFERENT MODES OF GENERATING INDUCED CUR- RENTS, AND THE LAWS WHICH GOVERN THEM...	52
Laws of Induced Currents	54
VARIOUS MAGNETO-ELECTRIC GENERATORS OF ELECTRIC LIGHT... ..	61
The Alliance Machine	62
Wilde's Machine	68
Ladd's Machine	71
Gramme's Machine	74
Siemens' Machine	82
De Méritens' Machine	85
Wallace Farmer's Machine	90
Brush's Machine	92
Bürgin's Machine	95
Trouvé's Machine	97
Lontin's Machine	98
MACHINES WITH ALTERNATE REVERSIONS OF THE CUR- RENTS, ESPECIALLY APPLICABLE TO THE DIVI- SION OF THE ELECTRIC LIGHT	100

	PAGE
Lontin's System	100
Gramme's System	104
Siemens' System	107
Jablochkoff's System	110
COMPARATIVE EXPERIMENTS ON THE EFFECTS PRO- DUCED BY THE DIFFERENT ELECTRO-MAGNETIC MACHINES	111
EFFECTS OF THE RESISTANCE OF EXTERNAL CIRCUITS...	120
RESULTS PRODUCED BY COUPLING TWO MACHINES ...	122
TABLE OF THE AMERICAN EXPERIMENTS... ..	123
COMPARATIVE TABLE OF THE ENGLISH EXPERIMENTS	124—5
TABLE OF NEW EXPERIMENTS (SHOOLBRED) ...	126—7
APPARATUS FOR EVOLVING THE ELECTRIC LIGHT ...	128
Light produced between carbon electrodes ...	128
<i>Jacquelain's Method</i>	131
<i>Carré's Method</i>	132
<i>Gauduin's System</i>	134
Effects produced by the addition of Metallic Salts to the Carbons prepared for the Electric Light	135
Metallized Carbons	137
Effect of heat on the conductivity of the carbons	139
Light produced by means of conductors of indifferent conductivity	140
<i>Jablochkoff's System</i>	140
<i>Lodyguine and Kosloff's System</i>	144
<i>Edison's System</i>	145
<i>Systems of É. Reynier, Werdermann, and others</i> ...	146
Light produced by means of an inductive action	150

PART III.—ELECTRIC LAMPS.

	PAGE
VOLTAIC ARC LAMPS	152
Foucault and Duboscq's Lamps	154
Serrin's Lamp	161
Siemens' Lamp	165
Lontin's Lamp	169
De Mersanne's Lamp	170
Bürgin's Lamp	172
Gaiffe's Lamp	174
Carré's Lamp	177
Brush's Lamp	178
Jaspar's Lamp	180
Rapieff's Lamp	181
Baro's Lamp	185
Wallace Farmer's Lamp	186
Houston and Thompson's Lamp	186
Molera and Cebrian's Lamp	187
Lamps of various kinds	188
<i>Regulators with hydrostatic actions</i>	190
INCANDESCENT LAMPS	195
King's and Lodyguine's Lamps	195
Konn's Lamp	196
Bouliguine's Lamp	198
Sawyer-Man's Lamp	199
E. Reynier's Lamp	199
Werdermann's Lamp	205
Trouvé's form of Reynier's Lamp	209
Ducretet's form of Reynier's Lamp	211
Tommasi's Lamp	212

Edison's Lamp	212
Automatic lighter of Reynier's Electric Lamps	216
ELECTRIC CANDLES	217
<i>Condensers</i>	227
Other Systems of Electric Candles	229
<i>Jamin's Candle</i>	231
<i>Soligniac's Candle</i>	236
<i>Lavaud de l'Estrade's Candle</i>	237

PART IV.—COST OF ELECTRIC LIGHTING.

Cost of the Electric Light with Batteries ...	239
Cost of the Electric Light with Induction	
Machines	242

PART V.—APPLICATIONS OF THE ELECTRIC LIGHT.

Application to Public Illumination	249
Application to the Illumination of Light-	
houses	259
Application to the Lighting of Ships	263
Application to Nautical Signals at long range	268
Application to the Arts of War	270
Lighting of Railway Trains	274
Application of the Electric Light to the	
Lighting of the Drifts in Mines, &c. ...	275
Application to Lighting Railway Stations,	
Workshops, &c....	278

	PAGE
Application of the Electric Light to Fishing	281
Application to Submarine Working	283
Applications to the Projections on a Screen of Optical Experiments, Photographic Transparencies, &c.	283
Public Trials of the Electric Light	289
Application of the Electric Light to Theatri- cal Representations	290

PART VI.—CONCLUSION.

REVIEW OF FOREGOING STATEMENTS	293
----------------------------------------------	-----

NOTES AND APPENDICES.

NOTE A.—ON THE INDUCTIVE ACTIONS IN THE NEW DYNAMO-ELECTRIC MACHINES	296
NOTE B.—ON THE DUTY OF GRAMME MACHINES ACCOR- DING TO THE RESISTANCE OF THE EXTERNAL CIRCUIT	302
<i>Internal Resistance of the Machine</i>	304
<i>Electro-motive Force</i>	304
<i>Intensity of the Current</i>	304
<i>Work transformed into Electricity</i>	305
<i>Utilizable Work in the External Circuit</i>	306
<i>Duty</i>	306
<i>Tension and Quantity Machines</i>	308
<i>Elements of the working of Gramme Machines</i>	308

CONTENTS.

XV
PAGE

NOTE C.—THE CRITERIA OF THE ELECTRIC LIGHT ...	309
NOTE D.—ON A NEW ARRANGEMENT OF THE WERDER- MANN LAMP	312
NOTE E.—ON EDISON'S NEW DISCOVERY	313

TRANSLATOR'S APPENDIX.—No. 1.

ENGLISH EQUIVALENTS OF THE FRENCH DENOMINA- TIONS USED IN THIS VOLUME	314
---------------------------------------------------------------------------------	-----

TRANSLATOR'S APPENDIX.—No. 2.

RECENT INVENTIONS	315
Incandescent Lamps	315
<i>Swan's Lamp</i>	316
<i>Maxim's Lamp</i>	317
<i>Edison's Lamp and Fox-Lane's Lamp</i>	317
The Faure Secondary Battery	317



ELECTRIC LIGHTING.

PART I.—GENERAL CONSIDERATIONS.

HISTORICAL SKETCH.

THE need of illumination in the absence of sunlight was felt by man in the earliest ages of the world, and the artificial production of light by fire, which he was able to discover, is even one of the great characteristics by which he is distinguished from other animals. At first he had for light merely pieces of burning wood, fragments of dry plants, or branches of resinous trees, of which he made torches; later he would notice the combustible and illuminating properties of certain oily liquids; and we see that the Hebrews, the Egyptians, and the nations of India and Upper Asia, were acquainted with the use of lamps at the most remote antiquity. But these lamps, even among the Romans, had smoky wicks, such as would not be used at the present day by even our rudest peasants. The tallow candles invented in England in the twelfth century, and not introduced into France until the reign of Charles V., were in the middle ages considered as a great advance in illumination, and lamps for lighting towns

date from but the seventeenth century (1667). It was only in the middle of the succeeding century that the famous *réverbères* (street lamps with reflectors) were invented, which in our youth we still saw hung in the middle of the streets in several towns. At the present time we have a great contempt for these means of illumination, and yet when Quinquet in 1785 invented the class of lamp that bears his name, it was supposed that he had made a magnificent discovery;* and I yet remember the enthusiasm which hailed Carcel's invention of the lamp with clockwork. It was, however, only at the period of the discovery by Lebon of the illuminating properties of gas, in 1801, that the revolutionary era of public illumination commenced; but although from the first the immense advantages of this method of illumination could be proved, the determination to adopt it required a long time. It was in England that the first applications of this system to the lighting of streets were made, and although the invention was entirely a French one, people did not bethink themselves of using it in Paris until 1818, under the administration of De Chabrol. The producers of lamp oil were at this time struck with dismay, for in this discovery they saw the ruin of their industry. But they soon found that, contrary to their expectation, the consumption of lamp oil increased with the development of gas illumination. It could not, indeed, have been otherwise, for gas illumination, by accustoming people to a brighter light, was bound to cause an increase in the number of lamps used for private illumination, and an improvement in the construction of the lamps themselves, so that for the same object they might burn a larger quantity of oil.

This retrospective glance shows us that at the present time the consequences which may result from the development of electric lighting are erroneously exaggerated. If this means of illumination should come to be produced under thoroughly

* It appears that Argant was the inventor, and that Quinquet merely improved the lamp by adapting to it the glass tube which acts as a chimney.

practical conditions, still many years will be required before it is generally adopted, and even then it cannot always be applied ; but as people become accustomed to that brilliant light which makes the gas-jets appear as dull as these before made the street oil lamps, it will be found necessary to increase the number of gas-burners in places where they are obliged to be used, and it may be that the consumption will even exceed that of the present day. We have already seen that the electric lighting of the *Avenue de l'Opéra* has stimulated the improvement of the gas-lights in the *Rue du 4 Septembre*, and there is no doubt that people will in future not rest satisfied with the present illumination.

Although the discovery of the immense luminous power of the electrical discharge taken between carbon electrodes is not new, it was only in 1842 that experiments were made of sufficient importance to enable the possibility of its employment as a means of public illumination to be foreseen. The results obtained at that period by Deleuil and Archereau in their experiments, carried out on the *Quai Conti* and on the *Place de la Concorde*, astonished all who witnessed them, and people already asked themselves whether by operating on a very large scale it might not be possible to produce artificial suns, each capable of illuminating a whole quarter of the city. But at that period the supply of electricity necessary for the production of the light involved considerable expense, the means of rendering the light uniform were very primitive, and competent persons had little faith in the possibility of applying it to public illumination. In 1857, however, the magneto-electric machines of the *Alliance Company*, originally constructed for a purpose quite different from the electric light, soon showed, after numerous improvements had been effected in it by J. Van Malderen, that this light could be produced under favourable conditions, and also that under such conditions it was, light for light, cheaper than gas. Thereupon the idea of applying it to public illumination was reverted to ; but the difficulty of dividing it and distributing

it over several places, the superintendence which it was necessary to bestow on the working of the electric lamps, and the irregularity of their action, discouraged even the most sanguine. It is only in quite recent times—after fresh improvements in the electric machines, in the carbons of the lamps, in the lamps themselves, and particularly after the interesting experiments made by the Jablochkoff Company in lighting streets and private establishments—that the question has again come to the front, but this time under infinitely more favourable conditions, which promise its speedy solution. To judge by the flutter in gas companies' stock in England, as well as in France and America, we may conclude that the matter has become serious, and that we shall probably in a few years hence witness the—at least partial—transformation of public illumination.

IMPORTANT DEFINITIONS.

Before entering into any detail on matters relating to the electric light, it appears to me indispensable to clearly lay down the meaning that must be attached to certain words which we shall often have occasion to use, and which, though perfectly precise and definite in their signification, are not always rightly understood, and hence much deplorable confusion often arises.

In the first place an *electric current* is, in fact, nothing in itself but a dynamical action or motion resulting from the destruction of electrical equilibrium in a conducting system, its effect being a tendency to the re-establishment of the disturbed equilibrium through the medium of another conductor. Consequently, if the cause which has produced this destruc-

tion of equilibrium is but momentary, the current lasts only for an instant ; it is in that case a *discharge*. But if the cause persists, the current becomes continuous, and may be compared to a stream supplied by a spring : this is the *electric current* properly so called.

As the effect of a current is to re-establish the equilibrium which has been disturbed at some point of a conducting system, it naturally follows that the two free extremities of the conducting system must be united in order that the current may show itself ; the system then forms a true *circuit*, which more or less resembles the circle, but which is always formed in the same way ; that is to say, the current having a certain direction at the point where the disengagement of electricity or destruction of the electrical equilibrium occurs, it will have the contrary direction in the opposite part of the circuit.

That which produces the destruction of equilibrium just spoken of is named the *electro-motive force*. The extreme partisans of the electro-chemical theory do indeed reject this expression, because it is associated with Volta's theory, which they will not accept ; but whatever theory may be adopted, this expression is entirely suitable ; for since an electric current is a phenomenon of motion, and every motion is the effect of a force, it is quite certain that in every circuit traversed by a current there is a force put in action, and this force may therefore be termed the *electro-motive force*.

The *tension* of a current, which is now often confounded with the *potential*, is the property of the electric fluid, which in a manner gives the impulse to the electrical movement, and which outwardly manifests itself by a tendency to act on the adjoining objects, and to produce the effects peculiar to static electricity. It is the quantity of electricity kept free at the poles of a battery when these are not connected, and which escapes recomposition during the time that the disengagement of electricity continues.

The *potential* of a source of electricity* is related to the tension; but, being applied to the electrical actions themselves, it may represent the tension under more defined conditions, which admit of numerical expression. It may be roughly defined by saying that it is to electricity what temperature is to heat; it is, in a manner, the *quality* of the electricity, and this properly has relation to the *quantity*. The notion of the potential of an electrified conductor necessarily originated from the study of the conditions of electrical equilibrium, according to the laws discovered by Coulomb. For the existence of these conditions of equilibrium it is necessary that the resultant of the attractive and repulsive forces acting upon an interior point should be *nil*; but it does not therefore follow that the action of the electricity spread over the surface of a conductor should also be *nil*; and it is the mathematical expression representing this action with the zero resultant that is called the electric *potential*.

The electrical *intensity* represents the magnitude of the effect produced by the electro-motive force, that is to say, the force of the current; it is, therefore, always in proportion to the *quantity of electricity* circulating in the conductor, and *it must depend upon the amounts jointly of the electro-motive force and of the resistance offered by the conductor to the motion of the fluids*. Ohm has shown that its value may be expressed by the ratio of the electro-motive force to the resistance of the conductor, and this supposes that it is *directly proportional to the electro-motive force, and inversely proportional to the resistance*. Again, Joule has shown that the heat developed by an electric current is *proportional to the time, to the resistance of the circuit, and to the square of the quantity of electricity which passes through the circuit in a given time*.

* Abria, in an interesting paper on the Elementary Theory of Potential, thus defines it:—"Let us call the *Potential* of an electrified body the indication of a torsion balance, in which the movable ball and the fixed ball are two small equal spheres, which, being in contact, have been connected with the body by a long and thin wire."

The *resistance* of a conductor represents the magnitude of the obstacles offered by its material particles to the free passage of the fluid : *it is the inverse of the conductivity*. This resistance depends, therefore, on the nature of the conductor and on its dimensions. Ohm has shown that this resistance is, for the same kind of conductors, *inversely proportional to the section of the conductor*, that is to say, to the surface obtained by cutting it perpendicularly to its length, and he also found that the resistance was *proportional to the length*, and *inversely proportional to the conductivity*. In conductors of indefinite mass like the earth, the resistance becomes *independent of the distance between the points where the circuit communicates with that mass*, and depends only on its mean conductivity and on the surface of the plates which establish the communication ; it may therefore be considered as *inversely proportional to the square root of that surface*.

As a circuit is usually composed of several different kinds of conductors, which therefore offer different resistances for the same dimensions, it becomes important, in order to estimate the *total resistance*, to reduce them all to terms of one and the same unit of resistance,* and when that is done, the resistance of the circuit is termed the *reduced resistance*. The laws established by Ohm relate only to reduced resistances. It ought always to be borne in mind that however different may be the several parts of a circuit, *the electric intensity of the current which traverses it is the same at every point*, but in each of its parts the tensions are different.†

* This unit of resistance has long been discussed, and at the present day electricians are still at variance as regards the one that should be adopted ; in general, however, the British Association unit is employed, to which the name of Ohm is given. This unit represents about 100 metres of telegraph wire of 4 millimetres diameter. We shall refer to these units again.

† According to the English formula of Latimer Clark, the following are the values of the resistances of the most commonly used metals, for 1 metre of length and 1 millimetre of diameter :—

	Resistance in Ohms.	Conducting Power.
Annealed Silver	0·01937	—
Drawn Silver	0·02103	100·00

The resistance of metals increases, however, with the temperature, while on the other hand that of liquids and gases decreases. The co-efficients of correction which must be applied to the figures we give in the table below in order to obtain the true value for a given temperature, may be seen in my *Exposé des applications de l'électricité*, tome I., pp. 37 et 453.

The *conductivity* of a body is its property of transmitting an electric current more or less easily. Properly speaking, all the substances of nature are conductors, but in very different degrees and under very different conditions. Metals are the best conductors. Resins, and other substances like India-rubber, gutta-percha, glass, &c., have less conducting power. Liquids and gases are also conductors, but under certain conditions.

The conductivity of bodies may be considered from several points of view. When it allows the electricity to penetrate the whole mass of a body without further action, and to be propagated within it like heat, it takes the name of *conductivity proper*. When, on the contrary, it results only from the effects of successive chemical decompositions and

	Resistance in Ohms.	Conducting Power.
Annealed Copper	0'02057	—
Drawn Copper	0'02104	99'55
Annealed Gold	0'02650	—
Drawn Gold	0'02697	77'96
Annealed Aluminium	0'03751	—
Compressed Zinc	0'07244	29'02
Annealed Platinum	0'11660	—
„ Iron	0'12510	16'81
„ Nickel... ..	0'16040	13'11
Compressed Tin... ..	0'17010	12'36
„ Lead	0'25270	8'32
„ Antimony	0'45710	4'62
„ Bismuth	1'68900	1'24
Liquid Mercury	1'27000	—
Alloy of Platinum and Silver	0'31400	—
German Silver	0'26950	—
Alloy of Silver and Gold	0'13990	—

recompositions, as in the case of liquids, it is termed *electrolytic conductivity*. Finally, when it requires for its existence a preventive action of condensation, such as takes place in the badly conducting bodies called insulators, it takes the name of *electro-tonic conductivity*. It is this conductivity which produces the effects of electro-static induction in submarine cables.

The majority of non-metallic substances, such as minerals, woods, the human body, tissues, &c., are conductors only by reason of their electrolytic conductivity; and their resistance depends, therefore, on their greater or less hygrometric power. Most metallic minerals, however, unite to this kind of conductivity a very marked conductivity proper.*

Finally, to finish these definitions, we shall state that by the word *electrodes* is understood the metallic plates which are plunged into an imperfectly conducting medium in order to electrify it intimately, and over a surface sufficiently large for it to acquire a certain amount of conductivity. The zinc and copper plates of a battery constitute electrodes, and the carbon pencils of an electric lamp are likewise the electrodes of the luminous arc between them.

Electrodes may also be used not only to communicate electricity to a badly conducting medium, but also to collect from it its polarity when it has by any circumstances become charged. In all cases there results from this system of electric communication a particular reaction, which is called *polarization*, and which, being produced in a direction opposite to that of the original electric action, disturbs the operation of the currents. This action is tolerably simple with liquids, but it is very complicated with minerals, and gives rise to peculiar and curious effects, which I have studied in detail,* but as these have nothing to do with electric lighting they must here be passed over in silence.

Most frequently polarization effects arise from electrolytic

* See the author's *Recherches sur la conductibilité électrique des corps médiocrement conducteurs*.

actions, that is to say, from deposits chemically produced on the electrodes, and reacting in their turn on the electrified medium. These deposits tend to produce an electrical action in the direction inverse to that of the current; but sometimes they proceed from an electro-static polarity communicated to the medium. A polarization of this kind is often produced in the voltaic arc.

We must also give some explanation of the word *condensation*, which we shall have occasion to apply more than once. What is so called is the accumulation of charge obtained by the inductive action which an electric charge produces on a second conductor of large surface insulated from the electrified one. In this action charges of opposite electricities are retained by their mutual attraction, so that they can be accumulated in quantities proportional to the extent of the condensing surface. Under these conditions a slight leakage of charge takes place by electrotonic conductivity, and as the condensing plates then constitute true electrodes, the resistance of the *insulator* or *dielectric* interposed between the two plates or *armatures* is *inversely proportional to the surface of these plates*; or, what comes to the same thing, if it be the effect on a submerged cable that is considered, *inversely proportional to the length of the cable*.

Electric Units.—In order to find the values of the electro-motive force, and of the resistance of a battery, as well as the values of the other elements acting in an electric circuit, it has been necessary to fix upon some units of electric measurement; and although scientific men are not yet of one accord as to the units which should be adopted, the tendency is to accept the “rational units” that, after long investigations, were fixed upon by the British Association.* These units have received different names, which keep in remembrance the physicists who have in the highest

* See the Report of the British Association for 1873, page 222.—(Tr.)

degree contributed to the progress of the science of electricity. Thus the unit of resistance has been called the *Ohm*; the unit of electric-motive force, the *Volt*; the unit of intensity of current, the *Weber*; the unit of electro-static capacity, the *Farad*. The multiples and sub-multiples of these units are designated by terms analagous to those of our metric system,* but under certain other conditions adapted to the uses oftenest made of them in their electrical applications. These terms are *mega* and *micro*, which respectively express a million of units and the millionth part of a unit; thus a million of ohms is called a *megohm*, and the millionth part of an ohm a *microhm*. The most generally used, however, of all these multiples and sub-multiples are the *megohm* and the *microfarad*.

We must now learn what these units represent.

The *ohm* practically represents the resistance of a column of pure mercury 1 square millimetre in section, and 1·0486 metre long, at the temperature of 0° Centigrade.* This is about the resistance of an iron telegraph wire 4 millimetres in diameter and 100 metres long.

The *volt* represents nearly the electro-motive force of a Daniell's cell, with sulphate of copper and water slightly acidulated, for if this be expressed by 1, the volt will be represented by 0·9268.

The *weber* represents the volt divided by the ohm.

The *farad* represents the capacity of an electric condenser placed under such conditions that the quantity of electricity carried by a volt through the resistance of one ohm would charge it to the tension of a volt. This kind of unit is little used except in the study of submarine cables. All the calculations relating to these units will be found in my *Exposé des applications de l'électricité, tome I.*, p. 432.

Measuring instruments graduated to these units can now be had at Gaiffe the Paris instrument maker's, *Rue Saint André*

* See the Translator's Appendix No. 1.—(TR).

des Arts, 40. These apparatus consist in the more or less complete action of resistance coils arranged like a set of weights, and in rheometres graduated in ohms and volts; so that by a simple reading, without calculation, the electro-motive force of a battery, its resistance, and that of the external circuit can be ascertained. The indications are not perhaps rigorously exact, but they are quite sufficient for the ordinary applications that have to be made of electric currents.

WHAT THE ELECTRIC LIGHT IS.

An artificial light is usually the result of a combustion, and we rarely think of a luminous effect without the intervention of a combustible substance. With the electric light, however, this is not the case, for it can be displayed in a vacuum, in water, and in gases incapable of supporting combustion. Whence arises this difference? From the fact that in one case the heat (which always accompanies the production of light), by effecting the decomposition of the combustible substance, gives rise to a disengagement of its constituent hydrogen gas that feeds the flame; while in the other case, the luminous effect is the result of a mere transformation of the physical forces. This transformation shows itself when the conditions of the passage of the electricity are such that, the free development of the electric action being impeded, an abrupt elevation of temperature takes place at one point in the circuit, and there manifests itself by incandescence without any combustion being required for the production of the incandescent effect. This phenomenon follows from the law which requires that, whatever may be the nature of the parts of a circuit, every

part must be traversed by the same quantity of electricity in the same time.

To obtain, therefore, a very marked calorific effect, we have only to cause the electric discharge to pass through a medium of insufficient conductivity, and this medium may be formed either of a good conductor made very slender, or of a gaseous conductor; but the luminous effect is always in proportion to the readiness with which the conductor becomes incandescent. If it is a solid, infusible and badly conducting substances may be used, such as platinum, and especially carbon, provided they have a length and thickness proportional to the electrical intensity of the current. We shall have occasion further on to study some electrical lamps based on this principle. When, on the other hand, the intermediate conductor is gaseous, the electrodes or solid rods conveying the current to it should be such that, while making it capable of conducting the discharge by the elevation of temperature they communicate to it, they may also be able to carry into the midst of this aëriform medium a vast quantity of extremely minute material particles, for the medium derives its luminosity from the glow of red-white heat communicated to these particles. It is known, indeed, that the flame of hydrogen gas, which is of itself not luminous, becomes so when spongy platinum is placed in it, or when the gas is charged with carbon.

These considerations have shown that carbon should be employed as the means for producing the electric light. This substance is a sufficiently good conductor of electricity; it is easily disintegrated, readily ignited, and being itself combustible, adds the luminous effect of combustion to the brightness of the electric light properly so called. Davy made the first experiments in 1813 on this method of producing the voltaic arc, and we shall presently see how this discovery was completed by Foucault, who substituted retort carbon for wood charcoal.

The electric light may also be obtained by means of solid

badly-conducting bodies rendered incandescent, and we shall have occasion to speak of a system of illumination of this kind, devised by Jablochkoff, who makes use of thin plates of kaolin. But in order to obtain these various results a source of electricity must be available, which not only supplies sufficient electricity to produce energetic calorific actions, but possesses a tension sufficiently powerful to overcome the resistances offered by the intermediate bodies that are to develop the luminous effects; and besides this the source of electricity must be suitable to the conditions of the experiment. It is obvious that if the gaseous interval interposed between the conductors of the discharge or current is considerable, it will be necessary for the generator of the electricity to possess tension especially, whilst to produce a powerful effect between two rather large carbons, separated by a narrow interval of air, quantity will especially be needed, since the calorific effects required to make the carbons incandescent are in proportion to the quantity of electricity produced by the generator.

These two different effects of electric generators may be readily explained by the way in which they operate in setting up the action. If the generator has a very great tension, such as occurs with Holtz's machine and the induction machines, the discharge may take place directly between the electrodes, which in a manner serve to determine it, leaping from one to the other; but as the enormous resistance presented by this gaseous interval very much diminishes the electric intensity, the light so produced is very feeble, and it can be increased only by decreasing the resistance of the gaseous medium, which may be done by rarefying it. The discharge then spreads itself in the vacuous vessel, and if the quantity of electricity be increased by means of a condenser a light of some intensity may be obtained. But this intensity will be considerable only when the discharge carries with it those material particles heated to reddish-whiteness, which, as we have already stated, constitute the whole brilliancy of

the electric light. If, instead of employing a generator of high tension, a generator of electricity *in quantity* is used, such as a battery, especially the battery with acids, the effects are different: the discharge cannot spontaneously be produced between the opposed electrodes if these be separated by even an extremely small interval. In this case it is necessary to bring the electrodes into contact, so as to develop a calorific effect, and since the surrounding gases are then made conductors by the heat, the electrodes may afterwards be separated from each other and the discharge be made to take place through the gaseous medium, but not with more than a very small separation of the electrodes.

It must not be supposed that any one source of electricity is especially suitable for producing the electric light: whatever the source may be, it can always be arranged so as to supply the desired effect. For instance, a battery is capable of giving tension effects if a large number of well insulated cells joined by their opposite poles are employed. Gassiot has succeeded in obtaining sparks with a battery of 3,000 small cells containing water only, each cell insulated by glass supports; and Warren de la Rue has obtained still more important results with chloride of silver batteries. In another direction, Gaston Planté, with his polarization batteries and his rheostatic machine, has succeeded in producing by voltaic discharges sparks of 4 centimetres in length. By a reverse method the *intensity* of a generator can be increased at the expense of its tension, by condensing its charges, or by arranging for quantity the elements which co-operate in the production of the electricity. Thus, an induction machine is able to give effects of quantity, if thick wire is used for the induced coil, and if the different coils brought into action are so connected that the induced currents, instead of passing from one coil to another, shall issue simultaneously from each individual coil, and all traverse the same conductor at once. In this case, as in the former, the preponderance of intensity over tension may be varied at will

by grouping the elements *in series*, that is to say, in such a way as to collect for tension a greater or less number of generating groups whose elements are themselves connected for quantity. But farther on we shall have occasion to recur to this important question; here we shall merely add that among the different generators there are some more advantageous than others for the electric light, as regards the energy of their action, as well as the expense attending them, and that the proper choice of a generator is one of the most important questions to be taken into consideration in connection with the electric light. Thus, among batteries, Grove's and Bunsen's are those which always yield the most advantageous results; and among machines the magneto-electric induction machines are those which must be used. Nevertheless unlooked-for improvements have in quite recent times made it possible to obtain the electric light with thermo-electric piles, and we shall see that if these apparatus could be made as substantial and durable as the experiments already made seem to warrant us to expect, this system would indeed be the simplest and most economical means of solving the problem of electric illumination. In the meantime, until proof of this has been brought forward, the induction machines must still be regarded as those which best answer the various requirements of the problem, and it is these that are at the present time almost exclusively used.

THE VOLTAIC ARC.

When the electric light is formed between two conductors separated by a stratum of gas, as shown in Fig. 1, it receives the name of *the voltaic arc*,* and under these conditions the

* The name of voltaic arc was given to the electric spark exchanged between two carbons, on account of the curvature of the luminous track when the stratum of air it traverses tends to rise under the influence of the high temperature to which it is subjected.

development of its brilliancy depends upon three concomitant elements: first, the intensity of the current; second, the nature of the electrodes; third, the nature of the medium in

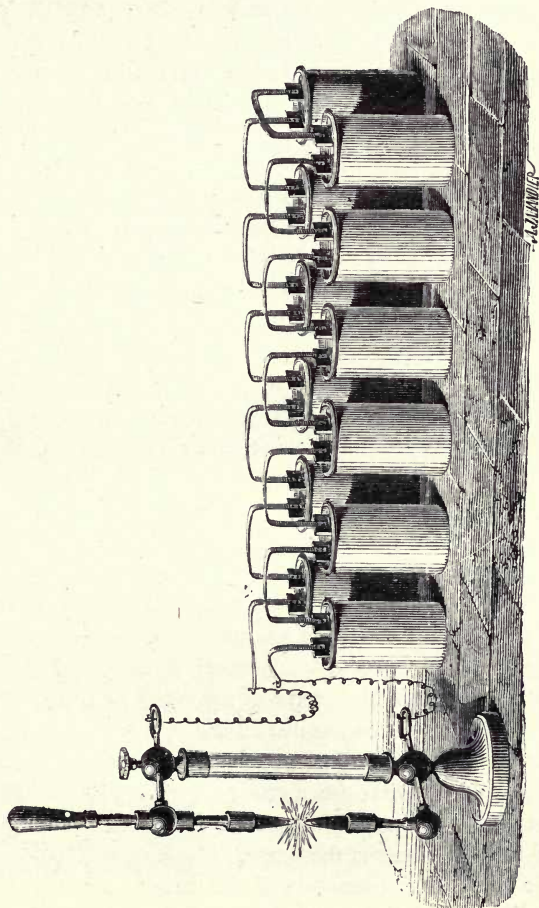


FIG. I.

which it is formed. These three elements affect also the colour of the light: for example, with zinc electrodes it is bluish; with silver, green; with platinum, red; and with

easily oxidizable metals, like potassium, sodium, magnesium, it is more intense than with the inoxidizable metals, such as gold or platinum. The shape of the luminous centre depends on the form of the electrodes and on their polarity, as I have shown in my account of Ruhmkorff's induction apparatus. Between a point and a conducting surface it assumes a conical form, and between two carbon points it has the appearance of a globe. The maximum length of the arc especially depends on the tension of the current, and with a strong current may reach to 2 or 3 centimetres when the arc has once been established. According to Despretz this length increases more rapidly than the number of battery cells employed, and the increase is more marked for small arcs than for large ones. It is, therefore, greater with batteries arranged for tension than with those arranged for quantity. Again, the voltaic arc is better developed when the positive carbon is above than when it is below; and when the carbons are horizontal the arc is shorter than when they are placed vertically, for the hot air always tends to ascend. On the other hand, the arrangement of the battery for quantity then becomes more advantageous than the arrangement for tension.

When voltaic currents are transmitted by carbon electrodes, the positive electrode has a much higher temperature than the negative, a circumstance which does not occur when induced currents of high tension are used to produce the light. With a moderate electric intensity, and with very pure carbons, the luminous effect emanates from a bluish radiant centre only; but when the intensity is greater, a real flame always surrounds that luminous centre, and the less pure are the carbons the larger is the flame.

Fig. 2 shows the appearance of the carbons producing the electric light when the voltaic arc is projected on a screen. Under these conditions the brightness of the flame, and that of the arc itself, are so far surpassed by that of the carbons that they can scarcely be distinguished. If the carbons are

conical they are unequally brilliant ; the positive cone is red-white to a considerable distance from the point, while the

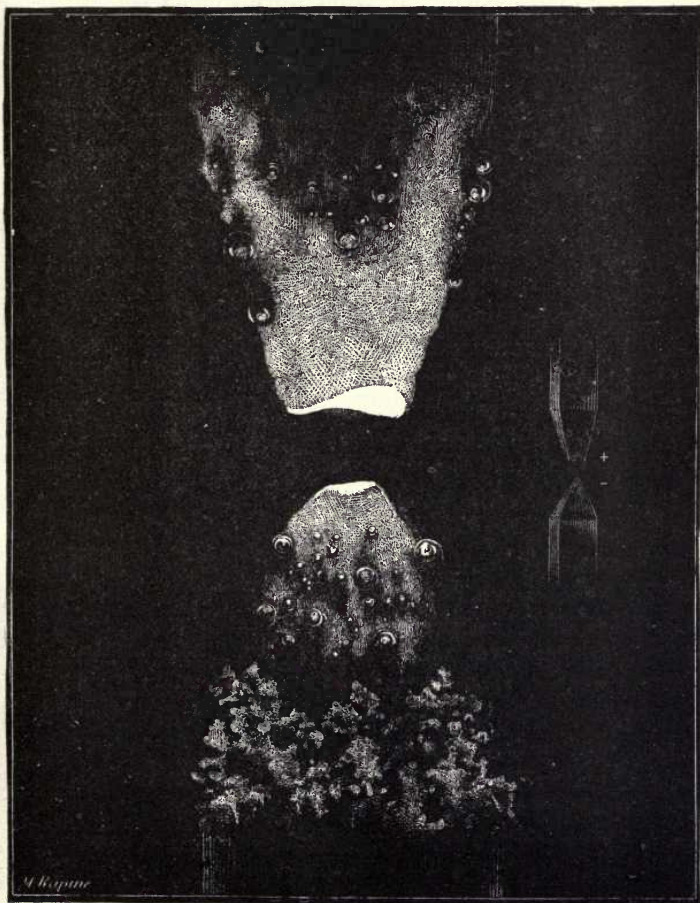


FIG. 2.

negative cone is merely reddened at its extremity ; and here and there on each of the carbons are seen incandescent liquid globules, which move about and glide to the point of

the carbon, whence they dart across to the opposite electrode. These globules are due to mineral substances, and, among others, to the alkaline carbonates usually contained in gas-retort carbons, which fuse under the excessively high temperature of the voltaic arc. These globules, which are not formed with very pure carbon, disturb the fixedness and constancy of the light.

When the voltaic arc is produced in the air the two carbons are soon consumed by burning, but on account of the different physical conditions of the two electrodes, and the transport of carbonized particles by the current, one of the electrodes—the positive—burns much more quickly than the other; and that in the proportion of two to one. This unequal consumption occasions several inconveniences: in the first place, a displacement of the luminous point, and, besides this, a disfigurement of the polar extremities of the two electrodes, one of which becomes more pointed, while the other is hollowed out in the form of a crater, thus surrounding the luminous point with a more or less prominent rim, which acts as a shade. The polarization effects induced on the electrodes themselves give rise to somewhat complex effects, which result in an elevation of temperature, and ought to be taken into consideration. With currents alternately reversed, like those supplied by the induction machines of the *Alliance* Company, these inconveniences do not exist; the consumption of the carbons is equal and regular, and their points, always remaining perfect in shape, give out the light in its entirety. With regard to this matter, what at first was supposed to be a defect in the magneto-electric machines, and a defect which must be corrected by means of reversing commutators, is, on the contrary, an advantage, not only by avoiding the loss of current which takes place through these commutators, but by the better conditions under which the work is produced.

These effects, however, have not been regarded in England in the same way as they have been by us, and in a report drawn

up in that country by a Commission of distinguished electricians, such as Tyndall, Douglass, Sabine, &c., it is stated that the concavity formed in the positive electrode can, by a proper disposition of the negative carbon, be made to furnish what is termed a *condensed* light, which considerably increases the light emitted in a given direction. Consequently, according to these gentlemen, the light supplied by rectified currents is much preferable

to that which results from currents alternately reversed. We give farther on, however, in a table drawn up by Douglass, the difference of intensity of the two lights, with or without rectification of the currents. In order to obtain the best possible effects it is necessary, according to Douglass, that the lower carbon, which is the negative one, should be placed as shown in Fig. 3, so that its axis may be in the prolongation of the side

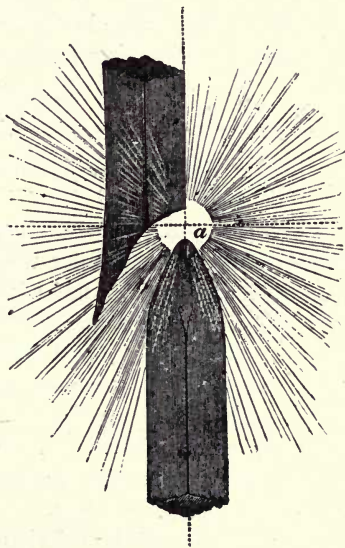


FIG. 3.

of the upper carbon, which faces the part of the horizon required to be illuminated; the concavity, the bottom of which is the most luminous part of the arc, then acts like a reflector, and its brilliancy is not concealed by the edges of the crater round the luminous centre. "On account of their loss of current and feebler action," says Douglass, "the machines of the *Alliance* Company and those of Holmes are far from being equivalent to the new machines with rectified currents, and in the application of the electric light to light-

houses it is better to use these last, for the angle within which the electric light has to be projected seldom exceeds 180° , and if the carbons are placed as stated above, the light is increased in a proportion the mean of which is 1.66 to 1. It is, of course, necessary that the positive carbon should be above, and the negative carbon below."

In a report made by an American Commission on the light produced by different induction machines, the following values are given for the luminous intensities yielded in different directions by this arrangement of the carbons:—

In front	...	...	2,218 candles, or 231.0 Carcel lamps.
On one side	...	578	" 60.2 "
On the other side	...	578	" 60.2 "
At the back	...	111	" 11.5 "

This gives a mean of 871 candles. Now the light produced by this same machine under the same conditions, but with the carbons placed in a line with each other, yielded an intensity of only 525 candles. "This would seem to show," says the report in question, "that an increase of nearly 66 per cent. of light is due to the arrangement of the carbons; but a close examination has shown that the fact is not so, and that upon the whole there is no advantage in using this arrangement except when the light is to be transmitted in one direction only."*

The resistance of the voltaic arc is rather variable, being dependent upon the state of ignition of the carbons, and therefore upon their size and the distance between them;

* In Douglass's report these differences of illuminating power were represented by the following figures (the illuminating power of the light produced by the carbons placed in a line being 100):—

In front	...	...	...	...	287, or 2.87 times stronger.
On one side	...	...	...	116	" 1.16 "
On the other side	...	...	...	116	" 1.16 "
Behind	...	...	...	38	" 0.38 "

The mean would therefore be in favour of the light emitted under the conditions we are speaking of, a smaller luminous power than that obtained by the American Commission.

but it may be assumed that under the conditions of a good light, this resistance may reach two or three thousand metres of telegraphic wire, say of 20 to 30 ohms. The figures given by different physicists are, however, far from being accordant; for while Preece, Schwendler, and others assign to the arc a resistance of 1 to 3 ohms, Ayrton and Perry fix the figures at from 20 to 25 ohms, at least with batteries; but it appears that with machines the resistance is less.

An interesting fact has been observed by Le Roux, namely, that if the voltaic arc is not formed in the cold when the carbons are separated by a layer of air, however small, it may be spontaneously developed from one carbon to another, across a space attaining nearly 3 millimetres, and after the current has been interrupted during a period which may last for about $\frac{1}{25}$ of a second. This explains why the alternately reversed currents of certain magneto-electric machines are able to yield a continuous light, although themselves discontinuous, for the current in the *Alliance* machines is periodically interrupted every one or two ten-thousandth part of a second.

We have stated that the voltaic arc depends much upon the medium in which it is formed. In a vacuum the length of the arc can be considerably increased, and although there is no combustion, there occurs a disintegration of the material particles of the electrodes, which are carried in both directions by the current, and even spread through the surrounding space. When the arc is formed in different gases its appearance varies but little; there are scarcely any changes of colour, but secondary chemical actions may occur, and then the length and colour of the arc will be modified. Of course, in gases incapable of supporting combustion the carbon electrodes, although becoming disintegrated, will not burn, but the brightness of the arc is diminished.

The electric light has a great analogy with that of the sun, but the former contains more of the chemical rays, a circumstance which renders it rather hurtful to the sight. Means of avoiding this inconvenience have indeed at various

times been proposed, and among others the use of fluorescent globes, capable of absorbing these chemical rays; but this improvement was obtained at the expense of the illuminating power, thus making the advantages of the electric light less marked.

In comparing different luminous sources with each other, Foucault and Fizeau have found that the light of the ordinary voltaic arc is one-half less than that of the sun, whilst the Drummond light (oxy-hydrogen) is only the one hundred and fiftieth part. Now the sun throws upon a given surface as much light as 5,774 candles placed at 0.33 metre from that surface.

PART II.—GENERATORS OF ELECTRIC LIGHT.

WE have seen that the electric generators which can be advantageously used for the electric light are batteries with acids, particularly Bunsen's battery, thermo-electric piles, and magneto-electric induction machines. Which arrangements of these generators are the best? This is what we are about to study in the present chapter.

VOLTAIC GENERATORS.

In the battery invented by Grove in 1839, two liquids are made use of: nitric acid on the one hand, and water acidulated with sulphuric acid on the other; and in order to place these two liquids in contact without mixing them, the one is poured into a vessel of half-baked porcelain, generally called a *porous vessel*, which is plunged into another vessel of glass or glazed stoneware. Vessels of earthenware or of crockeryware are of no use, on account of damage they receive from the action of acids, and from the crystallization of sulphate of zinc which forms inside of the pores of those substances.

The nitric acid is generally placed in the porous vessel, and water, acidulated to a tenth of its weight, in the glass vessel; then the positive electrode which gives the negative pole is formed by a plate of amalgamated zinc rolled into a cylinder, within which is placed the porous vessel. The negative electrode is formed of a prism of retort carbon, cut

out of one of those residues which are taken from the retorts of gasworks after the distillation. This form of carbon is very hard, very compact, and relatively a good conductor. The communicating wires are joined to these electrodes by two brass clamps, the one of large size covering the upper part of the carbon and pressed against its surfaces, the other provided with a binding screw aperture for holding the nega-

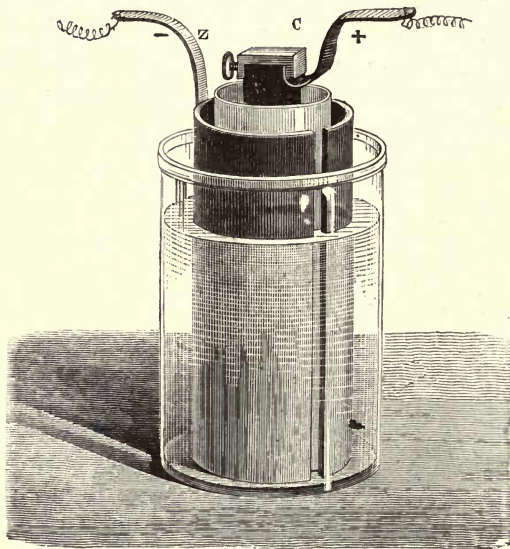


FIG. 4.

tive wire is applied to a slip of copper riveted to the zinc cylinder. The arrangement of a cell of this battery is shown in Fig. 4.

This arrangement may be reversed, and as regards the constancy of the battery there would be a gain in doing so, for, as I have shown, the effects of polarization are less in proportion as the negative electrode is larger; but as the electric light requires a great consumption of zinc, this substance must be placed in the cell in sufficiently large quantity,

and the former arrangement is the most advantageous in this respect.

In Bunsen's cell nitric acid acts as a depolarizing agent, that is to say, as a means of preventing a deposit on the carbon of the hydrogen resulting from the decomposition of the water by the zinc. When this deposit is formed on the carbon, there is, in fact, an electro-motive force developed in consequence of the reaction of the hydrogen on the liquid, which force, acting in the contrary direction to that of the battery, weakens the latter the more the longer the current is in action, and the less resistant is the circuit. Now nitric acid, being very rich in oxygen, and readily giving it up, permits the hydrogen disengaged in the cell to combine with that oxygen, and, so to speak, intercepts it on its passage before it is able to produce its bad effect. On the other hand, this acid, by itself acting chemically upon the acidulated water, develops an electro-motive force which acts in the same direction as that produced by the oxidation of the zinc, and this still more increases the energy of the battery.

The inconveniences of this battery are its expense and the suffocating and unhealthy emanations from it. The nitric acid, on being deoxidized, passes into the state of nitrous acid, which is liberated in the form of reddish-brown vapours that are difficult to prevent.

In order to avoid too great a consumption of zinc, and to render the action of the battery more constant, the metal is amalgamated, the special purpose of this operation being to annul the local couples which are due to the impurity of the zinc, and consume it without any useful result. The simplest means of obtaining this amalgamation is to plunge the zinc into a liquid composed in this way:—

Two hundred grammes of mercury are dissolved by heat in 1,000 grammes of *aqua regia* (nitric acid 1, and hydrochloric acid 3). When the solution of the mercury is complete, 1,000 grammes of hydrochloric acid are added.

The zinc is allowed to remain for a few seconds in this

liquid, and is then withdrawn completely amalgamated, and with 1 litre of the liquid 150 zincs may be amalgamated.

The zincs are also amalgamated by plunging them into a vessel filled with water acidulated with hydrochloric acid into which some mercury has been poured, and by rubbing them with a metallic brush dipped into mercury. But it is best to use zincs amalgamated throughout their whole mass. Dronier has succeeded in forming zincs of this kind by uniting mercury to the zinc during its fusion in a closed vessel.

Tommasi has recently arranged Bunsen's cell in such a manner as to produce the electric light under relatively good conditions. According to an article published by Moigno in *Les Mondes* of the 24 *Juillet*, 1879, Tommasi has even succeeded in making this battery inodorous by hermetically closing the porous vessels containing the nitric acid. The upper part of these vessels is enamelled, and serves as a reservoir for a certain quantity of the liquid that is periodically renewed by means of an opening which is again closed up, and a combination of syphons to maintain the contents of the outer vessels at the same level. An upper vessel containing a part of the acidulated water permits it constantly to flow in small quantity into the first of the outer vessels, distributes it by the syphons to all the cells of the battery up to the last, and this discharges its overflow into a vessel which leads it into a waste-pipe. The zincs stand in a small circular trough placed in the acidulated water, and containing mercury to keep up the amalgamation.

"After three months of constant experiments and observations," says Moigno, "we have been able to ascertain that the expenditure of the battery for a lamp by incandescence is about 1 litre of nitric acid and 2 litres of acidulated water a day, and the expenditure of the lamps is from 15 to 20 centimetres of carbon per hour."

We must add that this arrangement of the battery is nothing very novel, and we have described several systems of this

kind in our *Exposé des applications de l'électricité*, tome I., p. 207, et tome V., p. 392.

There are two important elements to be considered in a battery—its *electro-motive force* and its *resistance*. We have at the beginning of this work defined what is to be understood by these two expressions. The laws of electric currents have been based on the constancy of those two elements, and hence the name of *voltaić constants* which has been given to them; but as a matter of fact, on account of the secondary reactions which show themselves, and of which polarization effects are the principal, this is far from being the case. Nevertheless, as the values of these constants must be known approximately for all the other electric applications, it has been necessary to calculate them, and I have indicated, in tome I. of my *Exposé des applications de l'électricité*, pp. 171 et 456, those which have been obtained by various physicists. As in the present work we have hardly more than one form of battery to consider, we shall merely state that the electro-motive force of the Bunsen cell represents in units of electro-motive force or in *volts* from 1·888 to 1·964; and its ratio to the electro-motive force of the Daniell cell is from 1·749 to 1·820. The resistance of the same cell (average form), which is composed of that of the liquid interposed between the polar electrodes, and that of the porous vessel and of the gaseous deposits produced by electrolytic action and polarization, varies from 50 to 150 metres of telegraph wire, according to the resistance of the external circuit. I say *varies*, because figures which are deduced from experiment appear to prove that this variation exists; but as this results from the effects of the polarization of the electrodes, and as it affects the resistance of the cell only because the rest of the circuit is discharged from it, it may quite as well be referred to the whole circuit as to one of its parts. However, as a resistance other than that which it really possesses cannot be given to the metallic circuit, it is convenient to attribute to that of the Bunsen cell the value of 50 metres when the

circuit has little resistance, and that of 100 to 150 metres when the resistance is large. The values which we have just given relate only to a cell with fresh liquids; but these are rapidly changed as the nitric acid becomes deoxidized and the acidulated water becomes charged with sulphate of zinc from the corrosion of the metal. To restore the condition of the cell it often suffices to pour a little water into the outer liquid, and to add to the nitric acid some concentrated sulphuric acid, which, having great attraction for water, dehydrates the spent nitric acid.

I enter into many details on this battery, and on all others, in the first volume of my *Exposé des applications de l'électricité*, and this renders it unnecessary to speak more about them here. Their profound study would be altogether beyond the purpose of this work; it is sufficient for us to describe the mode of arranging the foregoing battery, in order that in the application which may be made of it to electric lighting it may be known upon what we have to rely.

In order to obtain the electric light with a Bunsen's battery, it is necessary to group together a certain number of cells, and the mode of grouping these cells depends upon the kind of light which it is desired to obtain. If the light is to be supplied by a voltaic arc, that is to say, with a gaseous interval between carbon electrodes, it is necessary to group the cells *for tension*, that is to say, by their opposite poles, a positive pole with a negative pole, as shown in Fig. 5, and at least 30 cells are necessary; generally 60 are used for most of the experiments that are made at theatres, or for the lighting of works by night, and even then only one lamp can be lighted. When it is desired to light several, a much more powerful battery must be used with certain lamps. We shall speak of this farther on.

If the light is to be the result of an incandescent effect, the battery gains by being arranged for quantity; that is to say, arranged in such a manner that all the cells are joined by their like poles. The calorific effects are then increased

at the expense of the tension effects, and for incandescence calorific effects are especially necessary.

Finally, if by reason of the resistance of the external circuit or the condition of the experiment, the electric current must have both tension and quantity, the cells are arranged *in series*, that is to say, in groups composed of a greater or less number of elements joined for quantity, and these groups are themselves joined for tension.

By means, therefore, of a battery of several cells or elements, we may obtain those various effects that are peculiar to batteries of a greater or less electro-motive force; but we must remember that when several cells are joined for quantity, that is to say, by their like poles, *we do not thereby increase the electro-motive force of the generator*; this electro-motive force always remains the same as that of a single cell, but *the resistance is diminished in proportion to*

the number of cells joined together, or, which comes to the same thing, a cell of larger surface is formed. It must also be borne in mind that the electro-motive force of a battery *does not depend on the size of its elements, but on the nature of the physical and chemical actions that arise within it, and on*

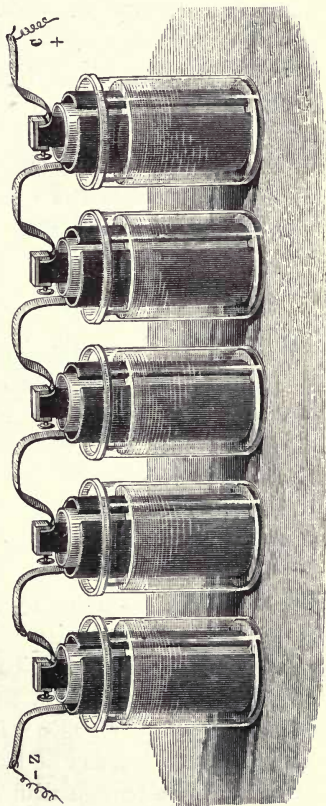


FIG. 5.

the number of elements that are joined by their dissimilar poles. But as this isolation of the action of each element increases the resistance of the battery as a whole, it may happen under certain conditions of the external circuit that more force may be lost by the increase of the total resistance of the battery than is gained by the increase in the number of its elements; and this is why it is necessary when determining the arrangement of a battery to know exactly the conditions of the external circuit on which the battery is to act, and more particularly the resistance of that circuit.

The great principle which must guide us is that the battery should be so arranged that *its own resistance shall be equal to that of the external circuit.* If the 50 metres of telegraph wire we have given be accepted as the resistance of a Bunsen's cell, and if the resistance of a voltaic arc in the ordinary electric lamps be estimated at 3,000 or 4,000 metres of such wire, it will be seen at once that there is an advantage in arranging for tension the elements of a battery used for electric illumination by the voltaic arc, and that at the same time it is an advantage to have cells of large size, not in order to give a greater electro-motive force, but to enable its action to last longer and to increase its calorific power. If the electric light is to be produced by incandescence, the resistance of the circuit becomes very much less (about 33 metres for the incandescent part); and there is a gain, on the other hand, in arranging the battery for quantity or in series, according to the number of lamps it has to supply and the arrangement of the circuits. It is certain that if in the same circuit a certain number of lamps be included, the battery must have more tension than when the lamps are arranged in distinct or *derived* circuits, and the mode of arrangement to be given to the battery will still be determined by the total resistance of the external circuit; which, in that case, will equal the resistance of one of the lamps divided by the number of lamps to be lighted. It will be understood that in this case the electricity supplied by the battery is simultaneously

distributed among all the circuits, as the water of a reservoir would be among several discharge-pipes, and that the resistance then opposed to the propagation of the electricity is equivalent to that of a single conductor of a section as many times greater as there are *derived circuits*. Now as the electric resistance of a conductor is in inverse proportion to its section, it will be at once seen why in this case the battery must be arranged in such a manner as to have its resistance greatly lessened.

It is not necessary that the several elements of a battery should be directly connected together; they may be joined by conductors of greater or less length. For instance, one part of the battery may be at one end of the circuit, the other part at the opposite end; and according to the manner in which these two parts are connected by the two conductors of the circuit, we shall have a battery arranged for tension, or with a double surface (quantity). Only in this last case will it happen that all the connecting wires between the two conductors will transmit the current with exactly the same intensity, at whatever point of the circuit the junction may be made. This will be easily understood, if we reflect that the connecting wires of the two parts of the battery then form electrodes charged to the same potential throughout their whole extent, and that the poles of the battery will then be placed at the two points where the wires are attached that are to supply the work.

If the resistance of the external circuit and that of an element of the battery are known, the most suitable arrangement for the elements of the given battery can be immediately determined without trial by means of the two following laws, which I have discussed at length in my *Exposé des applications de l'électricité, tome I.*, p. 145.

1°. The number of elements in each group to be arranged for quantity is given by the whole number nearest to the square root of the product of the total number of elements in the battery into the resistance of a single element, divided by the resistance of the external circuit.

2°. The number of groups which must be connected for tension is given by the whole number nearest to the square root of the product of the total number of elements in the battery into the resistance of the external circuit, divided by the resistance of a single element.

One of these determinations will, however, suffice, for if it be known how many elements are to be connected for quantity in each group, the total number of elements divided by that of each group will give the number of groups that must be connected for tension.

The amount of the resistance of the external circuit is ascertained by employing an apparatus known as the *Rheostat*, and a kind of electrical balance which may be a *differential galvanometer* or a *Wheatstone's bridge*. These pieces of apparatus, and the mode of using them, being described in all treatises on physics, and particularly in our *Exposé des applications de l'électricité*, we shall not further occupy ourselves with them : we shall state only that the total resistance of the derivations of a circuit may be obtained by the following equation :—

$$\frac{1}{T} = \frac{1}{d} + \frac{1}{d'} + \frac{1}{d''} + \frac{1}{d'''} \text{ \&c.}$$

in which T represents the total resistance, d, d', d'', d''' , &c., the resistances of the several derivations. From this the value of T can be calculated when we know the values of $d, d', d'',$ &c., or the value of any one of the derivations can be found when we know that of the rest and of T.

I should have wished, in such a work as I am now writing, to avoid mentioning these different calculations, but as they are indispensable if we wish to understand the question, and besides are very simple, I have considered it my duty at least to indicate them. Further, there is a general principle which is found in nearly all electrical effects capable of a maximum, and which ought always to be present to our minds. It is this : in order to be under the best conditions, the electrical generators must be arranged in such a manner

that *their internal resistance shall be equal to that of the external circuit*; and if the circuit is composed of two parts, one serving simply for electric transmission, the other for the production of a calorific or electro-magnetic work, it is necessary that *the resistance of the inactive circuit, including that of the battery, shall be equal to the resistance of the electro-magnetic organ*, or to that of the conductor developing the calorific effect.

Mode of Propagation of Electricity.—Before studying the magneto-electric generators, which have solved the problem of electric lighting, it seems to us important to give some details as to the conditions of charge and discharge in a circuit, and as to the mode of propagation of a current.

It is often asked in what conditions are the insulated wires of a circuit in connection with the battery when that circuit is not *closed*, and one would be apt to suppose that in order to produce a movement of the charge it would only be necessary to put a conductor in communication with one or other of the electric poles. But matters do not happen quite in this way.

To charge conductors it is necessary that the positive and negative charges shall be able to flow in the same proportion. Thus, a very long conductor applied to the positive pole of a battery can be charged only when the negative charge can be transmitted to a conductor of the same length attached to the negative pole, or when that charge is able to flow away into the earth. Then the charge is successively transmitted to the end of the positive wire, and when it has there reached the same tension as near to the battery, the current which resulted from that transmission ceases, and the whole of the conductor is charged to the potential of the battery. When this positive wire is placed in communication with the ground a new electric movement is produced, beginning at the end of the wire, and a discharge current is obtained which now is continuous and constitutes the current properly so called.

It follows from this mode of action that when a complete circuit is closed near the battery, the current at first sets out from the two poles of the battery, and produces its effect in the centre of the circuit last; so that at the first instant one-half of this circuit is traversed by a positive charge, and the other half by a negative charge. But this takes place only when the circuit is wholly metallic. If the earth is interposed the positive charge traverses the whole length of the wire, for the negative charge is then completely absorbed by the earth.

For a long time it was supposed that the charge of a circuit was in a manner instantaneous, and that it had its limit of velocity only in that of electricity itself, a velocity which was believed to approximate to that of light; but a deeper study of the mode of propagation of electricity showed that this was far from being the case, and that, in fact, properly speaking, there was no such thing as a velocity of electricity, but rather a period of electric fluctuations during which each point of the circuit incessantly changes its electric tension. Hence we were led to assimilate the propagation of electricity to that of heat, and for the first time were able to form a clear conception of the effects of electric transmission on our long telegraphic lines.

It was in 1825 that the illustrious Ohm made the discovery upon which he founded the theory which bears his name, and which modern discoveries have only served more fully to justify. Nevertheless, this theory was not at first received by the scientific world with that favour which its author had a right to expect; he was on account of it even subjected to a persecution that compromised his position as professor; and it was only ten years later, when Pouillet had arrived at the same laws by experiment, that people began to revise the sentence they had pronounced against Ohm and to appreciate the merit of his discovery. Yet while adopting the formulas of the illustrious mathematician, physicists were, until the year 1860, unwilling to accept the

assimilation of the mode of propagation of electricity to that of heat as propounded by Ohm, and on account of the position they thus assumed they arrived at such discordant results regarding the velocity of electrical propagation, that they were obliged to admit that either the experiments made for the measurement of that velocity had been badly conducted, or that the commonly accepted ideas on the propagation of electricity were false.

About the year 1859, Gaugain, a skilful physicist, who had for some time been engaged in verifying Ohm's laws as regards the transmission through badly conducting bodies, investigated the causes of this discordance, and soon found the solution of the enigma. He ascertained that electricity, so far from being propagated like light with a constant initial intensity in every part of its course, must, on the contrary, as Ohm had found, be transmitted in the same manner as heat is propagated in a bar of metal heated at one end and maintained at a lower constant temperature at the other end. In this case the heat is communicated from particle to particle beginning at the heated end of the bar, and in proportion as the calorific movement is propagated towards the other end, the parts first heated acquire a greater and greater quantity of heat, until when the calorific movement has reached the cold end, the different points of the bar lose as much heat on the one side as they gain on the other. Only then is the calorific equilibrium established, and the distribution of heat in all parts of the bar remains constantly the same. This is the condition called by physicists *the permanent calorific state*. But before a metallic bar arrives at this condition, there must elapse an interval of time, longer or shorter, according to the calorific conductivity of the bar, during which time each point of the heated body is continuously changing its temperature. If the assimilation of the propagation of heat to the propagation of electricity be correct, a like *variable period* must exist during the first moments of the propagation of a current. According to this hypothesis an electric current is, in fact,

nothing but the result of the tendency to equilibrium, from one end of the circuit to the other, of two different electrical states, determined by the action of the battery, and representing, therefore, the two different temperatures of the heated bar. This variable period must no doubt be excessively short on account of the subtilty of the electric fluid, but with circuits of great length and with those formed of bad conductors it may be measured, and this, in fact, Gaugain found by experiment. He thereupon investigated the laws of the transmission of the current during this variable period, and, among other laws, he found that the time required for a current to attain its permanent condition in a circuit, that is, to acquire all the intensity of which it is capable, is *proportional to the square of the length of the circuit*. This had not only been foreseen by Ohm, but had even been mathematically formulated by him in the equation representing the tensions of the different points of a circuit during the variable period of the current's intensity.

THERMO-ELECTRIC GENERATORS.

The thermo-electric piles invented by Seebeck in 1821 had for a long time been regarded merely as generators of great constancy, capable of being very advantageously used in scientific experiments, but incapable, on account of the weakness of their currents, of being applied in practice. But the application which, some years ago, Marcus made of the considerable thermo-electric power of metallic alloys, *

* The discovery of the great thermo-electric power of metallic alloys was made in the first instance by Seebeck, who even mentions the alloy of antimony and zinc as one of those which might be most advantageously used ; but these thermo-electric systems were not applied until ten years afterwards,

and the possibility of heating them to a high temperature without damaging the pile, made the question of thermo-electric batteries enter upon a new phase, which was cultivated with success by several physicists, and particularly by Farmer, Bunsen, Ed. Becquerel, Clamond, Noé, &c. Piles could then be obtained having an electrical intensity comparable to that of the battery cell with acids, and these piles were used with much advantage, even in electrotyping. Of all the apparatus of this kind, those which gave the greatest effects were beyond dispute Clamond's piles.

From the first, that is to say, in 1870, Clamond foresaw that he might one day be able to obtain the electric light with this kind of battery; and here is what I said about it in my *Exposé des applications de l'électricité, tome I.*, p. 426, published in 1871:—

“Mure and Clamond are now constructing batteries of this kind having 1,500 large elements, which they assert to have a power equal to 50 Bunsen cells. If, as everything leads us to expect, the expense occurs under the same conditions as in the case considered (heating by coke), it will be about 30 centimes per hour, and the thermo-electric pile may thus become an economic source of electric light.”

This result, however, could not be attained, on account of the unfavourable conditions under which the pile was placed, and because the galena which Clamond then used was damaged by the heat. Nevertheless, these experiments

and the combination which develops the highest electro-motive force is that pointed out by Ed. Becquerel, in which one of the bars is composed of antimony and cadmium in equal equivalents, and the other bar of bismuth and antimony, the last forming only a tenth part of the alloy. For scientific researches this combination gives the best results, but for industrial applications it cannot easily be used. In the first place, the cost of the apparatus would be extremely great, and secondly, the system could not be subjected to so high a temperature as one formed of other alloys. Therefore the combination of antimony and zinc with sheet-iron, adopted by Clamond, though not of itself giving so great an electro-motive force, is capable of yielding better results by reason of the greater difference of the temperatures that may be imparted to it.

sufficed to convince him that the problem might one day be solved, and this, in fact, is what we now see. In order, however, to arrive at a result so important as that which we have stated, Clamond had to devote himself to a great number of experiments and numerous investigations, and it was only after nine years had passed that he was able to solve the problem completely. One of Clamond's piles, arranged nearly like a heating apparatus, and having its dimensions not greater than 1'50 metres in height and 80 centimetres wide, is now able to supply three electric lamps, each equal to from 15 to 20 gas-burners, and requiring for the whole expense of the supply of electricity, the burning of only 9'5 kilogrammes of coke per hour. It will be seen that this is a considerable result, and the more important since an apparatus of this kind does not require the attention of a mechanic or skilled workman. The apparatus may be placed in a cellar and so arranged that it may be used as a heating apparatus, and any person is able to work it, since it needs only to be heated like an ordinary stove.

But let us state on what principle this ingenious apparatus is founded.

If pieces of two different metals are soldered together by one end of each, and the soldered portion be heated, the movement of the heat takes place differently in the two metals, and gives rise to an electro-motive force which supplies an electric current that may be collected from the free extremities of the metals. The simple metals, the junction of which affords the most marked thermo-electric effects, are bismuth and antimony; but, as we have already said, alloys and certain metallic minerals give effects much more powerful. At first Clamond's pile was made of bars of galena soldered to plates of sheet-iron; but he soon had to abandon the use of galena, and he resorted to an alloy composed of antimony and zinc, while still retaining sheet-iron as the electro-positive plate. By arranging these elements in a ring, placing several of these rings one above the other,

and throwing the flame of a central fire on the different junctions of the elements within the rings, he was able to obtain with a battery of somewhat small dimensions an electric current equally powerful with that from two Bunsen's cells. But in this arrangement the electro-motive force of the couple was in proportion to the difference between the temperatures at the ends of each bar, and therefore, in order to obtain a powerful effect, it was necessary that the bars should be rather long, and this led to a great increase of the resistance, for these heated alloys have much more resistance than would at first be supposed. The apparatus also required a useless consumption of the heat, which, by radiation and by contact with the air, escaped from the lateral surfaces of the prism without having traversed the whole length of the bar, and therefore did not yield the maximum of the useful effect of which it is capable as regards its transmutation into electricity. Again, it often happened that the apparatus received an excess of heat, and the metal fused round the parts of the iron plates to which it was soldered.* For these reasons Clamond was unable to use this kind of pile for the great effects he was seeking to realize. He had, therefore, to completely alter the original arrangement of his pile, and after numerous attempts he arrived at the very remarkable arrangement we are going to describe. The original Clamond piles are, nevertheless, still used at the present day in the workshops of Goupil and others, where they continue to work with regularity.

"In my new arrangement," says Clamond, "I have striven to avoid all the defects previously enumerated, and for this object I have formed the apparatus of three entirely distinct parts.

* "The use of flames or of radiating surfaces," says Clamond, "renders the heating of the couples very difficult to regulate, and it is seldom adopted except for apparatus of small dimensions, and when gas is the combustible. Besides, the surfaces to be heated (which are represented by the sections of the couples or of the polar projections with which they are sometimes provided) being very small, but little of the heat produced by the flame is taken up, and the products of combustion pass off at a very high temperature."

"1°. Of a *collector*, which is a series of light pieces of cast iron of such shapes that they present a succession of canals in which circulates the heated air supplied by any source of heat. These pieces present a very large surface to the motion of the hot gases, which leave them at a temperature but little removed from their own; they store up the heat which they afterwards communicate to the couples.

"2°. Of a *diffuser* of the caloric forming the outside of the apparatus, and made of metallic plates, presenting a considerable surface for the circulation of the surrounding air.

"3°. Of the *thermo-electric arrangement* properly so called, which is placed between the collector and the diffuser, so that the opposite series of junctions participate in the different temperatures of these two organs. The flow of heat takes place from the collector to the diffuser through the couples, parallel to their length, and without appreciable loss of heat by the lateral surfaces, thus realizing the maximum amount of transformation of which the substances used are capable."

These several plans have been realized in the apparatus represented in Fig. 6, the arrangement of which also admits of being varied.

In this apparatus the collector is formed by a cast-iron cage T O P, arranged nearly like a stove for smoothing irons, underneath which is the fireplace F, wherein coke is burnt. This cage is so formed that the current of hot air which is to supply the heating effect, after having thrice circulated about the apparatus by means of the chambers T O P, escapes by the draught chimney A, and may, by means of stove-pipes properly arranged, be used to warm a room. Externally this cage forms a polyhedric surface of many faces, on which the thermo-electric piles c are arranged in rows as shown; and upon these rows the diffusers D are applied.

The diffusers are made of plates of copper arranged like the leaves of a book, and are soldered on flat bands of the same metal, which by means of screws are pressed firmly against the rows of the thermo-electric couples. These plates, by the large surface of contact they present to the air,

readily part with much of the heat communicated to them, and thus occasion a great difference of temperature at the opposite junctions of the thermo-electric elements. These diffusers enable the length of the thermo-electric elements to

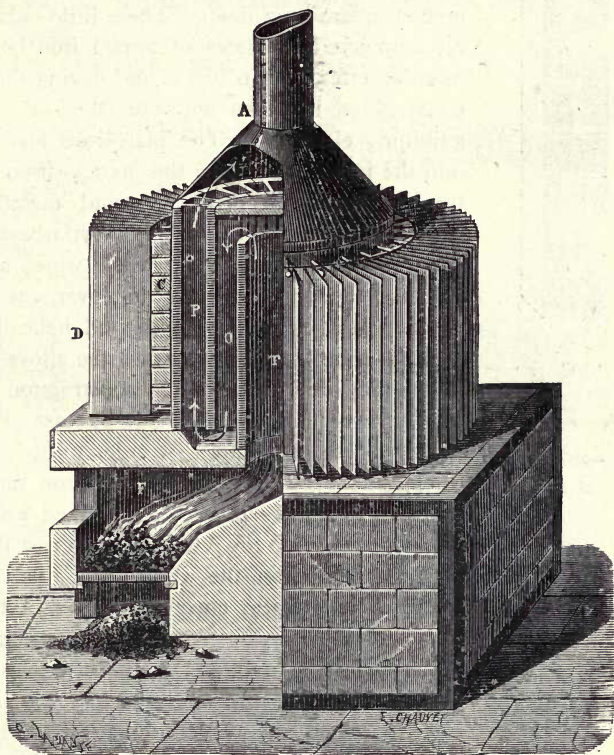


FIG 6.

be reduced without inconvenience. It will also be readily understood that the diffusers, on account of their large radiating surface, will emit much heat, and thus render the apparatus capable of being used as a source of heat, or as a stove for warming an apartment.

The thermo-electric elements are, as we have seen, arranged so as to form rows, and they appear as shown in Fig. 7. The negative elements, instead of being made of small elongated



FIG. 7.

prisms of alloy (antimony and zinc), are reduced to little almost cubical blocks, 3 centimetres square by 2 deep. These little cubes are connected by plates of tinned iron bent like the letter Z, as in Fig. 8, and having their ends soldered on the opposite faces of two adjoining elements. The plates are locked into the joints formed by the juxtaposition of the cubes, and in order to avoid metallic communication they are covered with asbestos paper. The parts of these plates which are soldered into the cubes are, moreover, cut so as to form a kind of teeth twisted helically, thus insuring good contact with the alloys to which they are soldered. The construction of

the rows is, however, very easy, for they can be cast at a single operation of any desired length. In order to do this it is necessary merely to place between two cast-iron rules

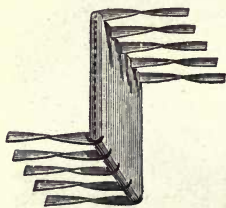


FIG. 8.

the series of sheets of tinned iron bent into the Z form, and to cast the alloy over the whole; the parts of the plates covered with asbestos paper separate the elements without further trouble. These rows, pressed between the collector and the diffuser, from which they are suitably insulated by a covering of asbestos

paper, as shown in Fig. 9, can be connected together by their free extremities, so that any desired connections and combinations may be effected.

Clamond has constructed two patterns of this kind of pile; one, which has for some time been at work at No. 25 in the *Rue Saint Ambroise*, lighting a workshop; the other, which

was put together in such a manner as to occupy less space, was intended for the electric light exhibition at the Albert Hall, London. The first form is 2·5 metres high and 1 metre in diameter, the second 1·5 metre high and 80 centimetres wide. This last form, instead of being cylindrical, is square, but it has the same electrical power, and is more compact.

The first form, represented in Fig. 6, comprises two distinct superposed piles, and the furnace is below exactly as shown in the figure.

In each half of the apparatus there are thirty rows of 100 elements, or 3,000 elements, making in all for the two superposed apparatus 6,000 elements. It is in the outer faces of these rows that the plates of copper which form the diffusers are fixed.

Each part of this pile can supply an electric light equal to 40 Carcel lamps. The total electro-motive force is 218 *volts*, or about 120 Bunsen cells; and the total resistance is 31 *ohms*, or 3,100 metres of telegraphic wire.* This large pile requires, as we already said, only 10 kilogrammes of coke per hour.

In the apparatus intended for the English exhibition the space is considerably reduced, and the rows of elements are so arranged as to form four different piles, each giving a current capable of producing a light equal to from 15 to 20 gas-jets. In this way four luminous centres are obtained instead of two.

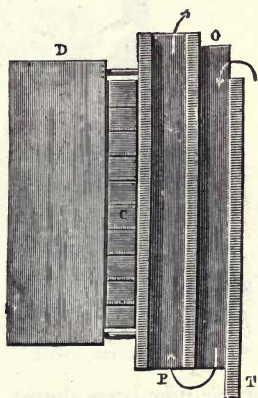
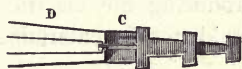


FIG. 9.

* These determinations were made by Cabanellas, the manager of the Electric Light agency.

MAGNETO-ELECTRIC GENERATORS.

The method of generating electricity by chemical action, and especially by the oxidation of zinc, is, as will presently be seen, extremely costly, and if this were the only way of producing the electric light, that method of illumination could not be entertained; but it is not the only way, for,



FIG. 10.

thanks to the powers of induction, generators of the light have been formed which require nothing more than motive power, and this brings the production of electricity to the matter of a greater or less consumption of coal, which is of all chemical reactions the simplest and cheapest. In this respect the results obtained have exceeded all expectations, and it may be said that if the solution of the problem depended only on the production of electric action,

it has now been almost realized; for, light for light, the cost of illuminating in this way would be ever so much less. But the question is, as will be seen, much more complex, and until we have treated it from the various points of view that require to be taken into consideration, the generators founded on the effect of induction will engage our attention.

History of the Question.—When a voltaic current circulates spirally round a core of iron, steel, or any magnetic substance, the latter is magnetized, and, with certain magnetic substances possessing, like iron, a non-persistent coercive force, this magnetism disappears as soon as the current

ceases to circulate in the metallic spiral acting as its conductor. This phenomenon, first observed by Ampère and Arago a short time after the discovery by Ørsted of the effects of currents on the magnetic needle, was the starting-point of electro-magnetism and of the majority of the mechanical applications of electricity.

By reasoning according to the principle of reciprocal actions, it might have been deduced *a priori* from this phenomenon that a permanent magnet by reacting on a closed circuit would cause an electric current in that circuit. Yet it

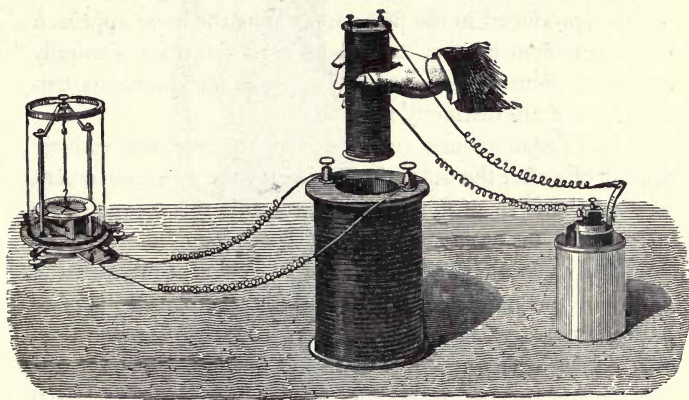


FIG. 11.

was ten years afterwards, that is to say, about 1830, that the illustrious English physicist, Faraday, first proved the existence of this phenomenon and determined its various characteristics. Numerous experiments instituted by Faraday on this subject showed that if a magnetic bar be thrust within a coil covered with insulated wire, or if a second coil traversed by a current be so thrust, as shown in Figs. 10 and 11, an energetic current capable of affecting a galvanometer is, in fact, induced in the first coil. But there was a somewhat peculiar circumstance which theory could not have enabled

one to foresee *a priori*, and that was that the current is merely temporary, for it ceases immediately, giving place to another current equally transient which shows itself at the instant the magnet is withdrawn from the coil. This latter current has its direction opposite to that of the former, and if the direction of these currents be compared with that of the magnetic or voltaic current which gives rise to them, it will be observed the directions are the same for the latter current and opposite for the former. Hence the name of *direct current* given to the current which shows itself in the second case, and the name of *inverse current* given to that which is produced in the first case. Thus the mere approach of a permanent magnet to, and its recession from, a spirally arranged circuit give rise to two opposite instantaneous currents which are distinctly separate.

These instantaneous currents may, however, successively appear one after the other, from one and the same movement of the inducer or of the induced circuit, if this movement is successive; for at each stage of this movement there is produced a differential induced current which continues the action of the former, and all these currents joining one to another may give rise to a current of appreciable duration, which may be in one direction or the other, according as the movements succeed each other in the direction of approach or in that of recession. This current, however, is feebler at any given instant than that which would result from the same total movement suddenly effected through the same space. We shall see farther on what is the effect of quicker or slower movements with respect to the nature of the induced currents developed by them; but here it may be stated that quicker or slower movements through the same space affect only the *tension* of the induced current.

When these principles were once recognized, it only remained to mechanically combine the different elements producing these temporary currents, so as to rectify them and cause them to succeed each other without interruption.

Several mechanics accomplished this, among others Pixii, Clarke, Page, Nollet, &c.; and for this end they had only to cause to revolve before a permanent horseshoe magnet an electro-magnet with two branches, wound round with a quantity of wire large enough to allow the inductive

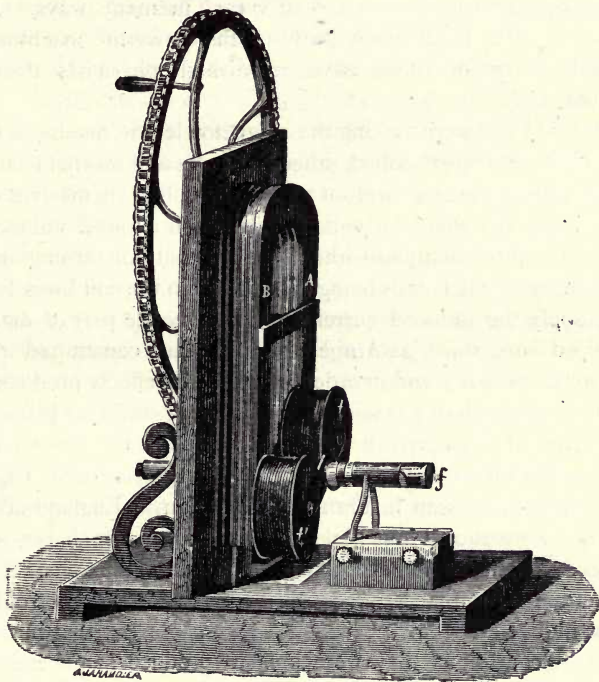


FIG. 12,

action to be developed in all its power. With this arrangement the electro-magnet is, in fact, magnetized on approaching the poles of the permanent magnet, and while becoming a magnet it produces in the wire surrounding it an inverse current, which gives place to a direct current as soon as the electro-magnet begins to lose its magnetism by receding. As

the ends of the induced wire, that is to say, of the wire of the electro-magnet, are connected with a commutator for reversing the poles placed on the axis of rotation of the system, the two currents traverse the circuit always in the same direction. Such are the magneto-electric machines, the original type of which is represented in Fig. 12, but their arrangement has, however, been varied in many ways. It is these that have given birth to the powerful machines which in recent times have astonished physicists themselves.

While some were making the magneto-electric machines of which we have just spoken, other physicists and mechanics were setting up new forms of them, by availing themselves of the inductive effects of voltaic coils which allowed induced currents to be obtained without the necessity of turning any machinery. Such coils being placed within the coil intended to supply the induced currents, could play the part of magnetized bars, since, as Ampère showed, they constituted *dynamical magnets*; and in order to obtain the effects produced by the approach or recession of the inducing coil (that playing the part of a magnet), it sufficed to place in the circuit an automatic interrupter of the current. By the year 1836 Page in America, Masson in France, and Callan in England had in fact constructed machines of this kind, in which the induced currents could be thoroughly studied and their character determined; so that it was established with certainty not only that induced currents possessed high tension, but that under certain conditions they were able to produce some effects resembling those of static electricity. These pieces of apparatus, improved by Page, Callan, Sturgeon, Gauley, Masson and Bréguet, Bachhoffner, Clarke, Golding Bird, Nesbitt, Breton, Fizeau, Ruhmkorff, Cecchi, Hearder, Bright, Pogendorff, Foucault, Bently, Ladd, Jean, Ritchie, Gaiffe, and Apps, were not long in becoming powerful generators of high tension electricity, able advantageously to supersede electric machines, and they constitute at the present day the most

important and most interesting class of apparatus from the power and variety of their effects.

From this rapid review it will be already seen that induction machines may be divided into two great classes: 1°, those which have for inducer a circuit traversed by a voltaic current, and in which the action is developed by the current itself; 2°, those which have for inducer a permanent magnet and require a mechanical movement to produce their effect. But besides these two classes of apparatus there is a third, the powers of which have recently been investigated, and which, while belonging to the second class we have just spoken of, present this curious difference, that the apparatus do not require permanent magnets to excite them, and that the inducer, made of soft iron, itself becomes a magnet, and a most powerful magnet, under the influence of the induced current it produces. The curious circumstance in these apparatus is that the initial cause is, so to speak, inappreciable; it is a slight magnetization communicated to the iron, either by the magnetism of the earth, or by a residual magnetism: in proportion to the working of the apparatus the initial cause and the effect are more and more developed until the limit of maximum magnetization of iron is reached. These interesting machines, devised almost simultaneously by Wheatstone and by Siemens, have been improved by Wilde and by Ladd, and have served to supplement many other machines contrived on different plans, which by this addition have acquired a very much greater power. Finally, to bring this historical sketch to a conclusion, we shall add that in quite recent times the field of investigation has just been extended in an unexpected manner by a new class of magneto-electric machines founded on the continual alternate reversal of the polarities successively developed in the different parts of an annular electro-magnet by a powerful magnet, and in the action exercised by this last on the wires of the coils passing before it. To this class belong the machines of Gramme, of Siemens, of Brush, of Bürgin, and

of De Méritens, which have furnished such marvellous results.

Of these various machines, it is evidently those which call a motor into play that are applicable for electric lighting, for it is in this form that electricity can be obtained under the most economical conditions. These machines will therefore exclusively occupy our attention ; but before this we think some indications should be given of the laws regulating induced currents, and of the different causes which concur for their production.

THE DIFFERENT MODES OF GENERATING INDUCED CURRENTS, AND THE LAWS WHICH GOVERN THEM.

Besides the induction effect which we have already explained, there are many other causes capable of developing induced currents. Every action, the effect of which is to diminish or to increase the power of a magnet already acting on an induction coil may give rise to induced currents which will be direct when there is diminution, and inverse when there is increase. This increase may result from the action on the magnetic poles of an armature of soft iron, and diminution will result from the withdrawal of that armature. Again, if the pole of a permanent magnet be passed before an iron core surrounded by a coil, a double action will be produced : 1°, a current which may be termed an *electro-dynamic induction current*, which will result from the successive passage of the spires of the induced coil before the pole of the inducing magnet, and which will be the more energetically developed the more suitable precautions are taken to avoid the hurtful induction to which the parts of the spires behind those directly affected by the magnet are liable ; 2°,

a current to which I have given the name of *polar inversion current*, and which results from the inversions of magnetic polarities to which the core is successively subject, by reason of the movement of the inducer.* These two currents

* In order that the origin of the currents which now play so important a part in the new electric generators may be thoroughly understood, we shall examine what takes place when a bar of soft iron surrounded by a magnetizing coil is brought near one of the poles of a permanent magnet, for instance, near the north pole. At the instant of approach there will be produced a first current, a current of magnetization, whose direction will depend upon which end of the bar is acted upon by the magnetic pole. This current is due to the transformation of the bar into a magnet. If the magnet is withdrawn, a current will again be induced in the direction opposite to the former, and which will correspond with the demagnetization of the bar. But if the pole of the magnet be brought near the *middle* of the bar, there will be no current produced, because the bar itself will then form a magnet with a *consequent point*, and the effect of the induction on the one side of this point will be counteracted by that on the other side. The same effects will ensue if the coil is deprived of the iron core. Now, it follows from this principle that, if the iron bar surrounded by its coil be bent so as to form a ring, neither currents of magnetization nor of demagnetization can be obtained by the approach or recession of the magnet, to what point soever it may be directed, for the parts to the right and to the left of the point affected are then polarized in the same manner. Nevertheless, if the magnet be moved parallel to the axis of the bar, that is to say, circularly about the ring, it will no longer be the same thing, and a current may be produced, due neither to magnetization nor to demagnetization, but which will, under certain conditions, last during the whole time the magnet is revolving in the same direction. This current may be the result of two different and simultaneous actions, but in order that it may be manifested it will be necessary for the coil to have a certain arrangement, for even if the induction be produced by a single magnetic pole, the two opposite parts of the ring affected would always be polarized in a different direction, and would give rise to contrary currents. One of these actions is the result of the magnetic disturbance produced in the core itself by the successive inversion of its polarities—a disturbance which must, as I have proved, give rise to a reaction analogous to that observed when an effect of demagnetization is made to follow an effect of magnetization under opposite conditions; and as under such conditions the resulting currents have the same direction, and in consequence of the progressive motion of the inducer they follow each other without interruption, a continuous current is the upshot, and this changes in direction only when the direction of the movement of the inducing pole is changed. The other action results from the motion itself of the magnetic inducing system before the spires of the induced coil, or what amounts to the same thing, from the motion of these coils before the inducing system. (*See Note A.*)

which are continuous, are manifested during the whole period of the magnet's movement, and their direction depends upon that of this movement, but it always corresponds with a demagnetization current, that is to say, with a current in the same direction as that of the magnetic current of the core affected.* It is these currents which act in the Gramme machines. The other reactions which were first discussed have given birth to magneto-electric machines, of which the best-known forms are those of Dujardin, Breton, Duchenne, Wheatstone, Bréguet, &c. ; but as these machines have not produced effects sufficiently powerful to form generators of electric light, we shall say no more about them.

There are yet other sources of induction which have promised to give origin to magneto-electric machines, and of their number is that which has given rise to the *peripolar* induction machine of Le Roux; but these sources are still too feeble to be applied advantageously.

Laws of Induced Currents.—Many experiments made on induced currents have proved :—

1°. That the quantity of electricity put in action in a circuit is proportional, other things being equal, to the intensity of the inducing current and to the length of the induced circuit.

2°. That it is independent of the duration of the inducing action, and varies only with the magnitude of the initial cause of induction.

3°. That the tension of the induced current varies on the contrary with the duration of the inducing action, and increases with the rapidity of the variation of the inducing cause; a circumstance which goes to show that the tension of an induced current is proportional to the algebraic derivative of the function of the time expressing the law of succession of the values of the intensity in the induced current.

* For the explanation of these effects see Note A at the end of the book.

4°. That the direct currents have a shorter duration than the inverse currents.

5°. That it follows from this last property that the inverse and direct currents, though formed by equal quantities of electricity, are able to act differently; for the direct currents having a shorter duration than the inverse currents, have a greater tension, and may therefore act on a circuit of greater resistance.

6°. That the duration of the direct current is independent of the resistance of the induced circuit, whilst that of the inverse current increases with that resistance and with the number of spires in the coil; whence it follows that in ordinary cases the electro-motive force of the direct current must be greater than that of the inverse current, and that the ratio of these forces increases with the length of the induced wire.

Induced currents may, like battery currents, be changed into tension currents or into quantity currents, not only according to the mode in which the induced coils are connected, but also according to the insulation of the wire, its thickness, its length, and the composition of the magnetic core causing the induction. With a wire very fine, very long, and insulated with all the precautions adopted for the electricity of the glass-plate machines, sparks of more than a metre in length have been obtained; and with a magneto-electric machine having a wire of large diameter a current may be obtained possessing sufficient quantity to produce the effects of the voltaic battery.

The laws of induced currents with regard to the effects they produce through the external circuit are the same as those of voltaic currents, but it must be admitted that in this case the resistance of the generator is represented by a quantity much greater than that which can be deduced from its direct measurement if voltaic currents were employed. Thus the calorific work supplied by an induction machine is expressed by Joule's formula, in which the value of the resistance of

the induced wire would be expressed by a quantity variable no doubt with the machines, but which may, with the *Alliance* machines, be six times greater than its true value. It follows then, that, taking into account this increase of resistance, this work is proportional to the square of the electro-motive force developed, and to the resistance of the external circuit, and is inversely proportional to the square of the total resistance of the circuit, and this leads to the conclusion that the maximum effect is obtained when the resistance of the external circuit exceeds that of the induced circuit by the quantity with which this last must be increased in order that Ohm's formula may be applicable to these machines.

We shall not speak of the laws relating to induced currents of different orders, for we shall have to concern ourselves but little about these effects in the machines used for electric lighting. But we must carefully study the influence on the induced currents of the shape, the dimensions, and the composition of the magnetized core, as well as that which results from the speed of the alternate magnetizations and demagnetizations.

If it is considered that the power of electro-magnets is proportional to the diameters of the magnetic cores, and to the square root of their length, it may be supposed that it would be of advantage to make the iron cores of induction apparatus the thickest and the longest possible. But as the alternations of magnetization and demagnetization are produced much more slowly with large iron cores than with small ones, and as again a cylindrical metallic surface allows of the formation of local induced currents which are developed to the prejudice of the induced currents themselves, some middle course had to be sought for, and recourse was had to bundles of iron wires or of juxtaposed thin plates of sheet-iron, the magnetic adherence of which is not sufficiently perfect to be equivalent to a continuous mass of that metal. This means has yielded excellent results, as we shall farther on have occasion to observe.

Experiments on the length of the magnetic cores have not yet been sufficiently multiplied and sufficiently conclusive to enable a very definite law to be formulated with regard to them. Poggendorff, Muller, and several other physicists have, however, observed in a simple coil with a straight core that the inducing action is stronger at the middle of the core than in any other point, and therefore they have advised that the greatest possible number of spirés should be accumulated on this part of the coil, which implies giving to the coils the form of a spindle. This result will be understood if it be considered that the middle of a coil corresponds with the resultant of all the dynamical effects of the individual currents of the magnetic core. As to the length of the coils themselves, it seems that there is an advantage in making them



FIG. 13.

rather long to obtain tension, and rather short to obtain quantity. Siemens, however, has contrived a form of induction coil entirely different from the ordinary forms, which has given excellent effects. It is represented in Fig. 13. The magnetic core is made of a cylinder of iron, in which a wide groove is formed longitudinally surrounding the cylinder, and in this the wire of the coil is wound parallel to the axis of the cylinder, and is bound with bands which prevent it from yielding to the influence of centrifugal force when the bobbin rotates. The parts of the iron cylinder left uncovered form the polar ends of the coil. The bobbin of course revolves on the axis of the cylinder, and in a semi-cylindrical cavity formed in the iron armature fitted to the two poles of the inducing magnet, as shown in Fig. 14. The two ends of the wire of the coil terminate in a commutator shown at the end

of the axis of the bobbin, on which press two springs connected with the circuit.

When it is wished to use cylindrical cores of iron there is an advantage, in respect to induction, to form them of iron tubes, slit longitudinally, and to put two or three of them one within the other. In the large machines of the Alliance Company this plan has been made use of.

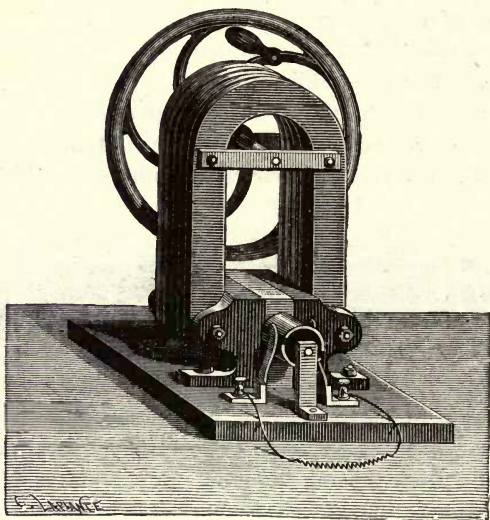


FIG. 14.

As to the more or less advantageous effects of quicker or slower alternations of magnetization and demagnetization, the question is complicated on account of the magnetic inertia of iron. According to the proportionality of the tension of the currents to the *derivative* of the function of the time, one would suppose that these alternations ought to be as rapid as possible ; but the tardiness with which iron is magnetized and demagnetized much complicates the effect produced, and it is observed that whilst slow interruptions of

the inducer are favourable to the development of the tension of the induced current in Ruhmkorff's coils, a high speed of rotation, and, therefore, very rapid alternations of magnetization and demagnetization, are required to produce the maximum effect with magneto-electric machines. It may, therefore, be said that in general a rapid succession of magnetizations and demagnetizations increases the tension of currents, and allows the magnetic cores to acquire their maximum of magnetization. It will be understood by this that the number of successive inducing effects which a machine will furnish, to be under the best conditions, will depend upon its construction, and that the more readily its magnetic organs are able to undergo magnetization and demagnetization, the greater should be its speed.

There are also certain conditions in the relative arrangement of the induction organs which are more or less favourable to a high speed; for example, in an ordinary magneto-electric machine formed of several induction coils the mean intensity of the sum of all the transmitted currents increases with the velocity of rotation, but in a less ratio than the increase of the velocity. This increase depends on two circumstances, that is to say, on the intensity of the current itself, and on the greater or less number of coils connected for tension. The greater the number of coils arranged for tension the less rapidly does the electro-motive force increase, and this slowness of increase is the greater as the intensity of the current is greater.

"It follows from all this," says Le Roux, "that the increments of intensity cost more and more when it is sought to obtain them by increase of velocity; for, if theoretically each turn consumes a quantity of work proportional only to the useful effect it will finally produce, practically such turn causes the loss of a certain quantity of work expended on passive resistance of every kind. Nevertheless, in the calorific applications of electricity, it is of importance to obtain these high intensities, since the useful effect is proportional to their square in a given time; but in the

chemical applications, for which the effect is proportional to the first power of the intensity, it is advantageous for the economy of motive force not to drive the machine at high speed."

If the increase of speed in magneto-electric machines augments the intensity of the resulting induced currents, on the other hand the increase in the intensity of the currents opposes the rotatory movement. The more frequent separations of parts attracting each other must give the motive power a greater sum of mechanical resistances to overcome ; but there is also in the very circumstance of the development of electrical work effected a mechanical reaction, which is the consequence of the transformation of the physical forces.

Everybody knows the beautiful experiment of Foucault's, which consists in making a copper disc revolve between the poles of a powerful electro-magnet. While the magnet is not in action the disc may be turned with any required velocity, but as soon as the electro-magnet comes into action the disc becomes more and more heated, the resistance offered to its rotation increases considerably, and soon becomes so great that the speed of the machine cannot be further increased. The calorific effect produced has therefore necessitated an expenditure of force by giving rise to an increase of resistance, and the measure of that additional mechanical resistance must be the equivalent of the physical action which has caused it. Now an action of this kind must evidently be produced in magneto-electric machines in rapid rotation, and especially in dynamo-electric machines.

There is yet an interesting question to study, namely, to ascertain the duration of induced currents, the period which elapses between the closing or opening of an inducing circuit and the appearance of the induced current, and how the intensity of the current behaves at the different phases of its appearance. Blaserna and Mouton have made some very interesting researches on this subject, of which we shall indicate the principal results.

According to Blaserna the time which elapses between the

inducing action and the appearance of the current is less than the fifty thousandth part of a second, and the current, feeble at the commencement, gradually increases, then diminishes, and ceases in a space of time varying with the intensity of the induced current, but which is on the average the two hundredth of a second. Mouton has shown that this diminution of the induced current takes place by oscillations successively decreasing.

To conclude, we shall add that if several induction effects can arise under the influence of the same inducer, *the total resulting current cannot have a greater intensity than that which would result from a single one of these effects*, if the action causing this last were acting under its maximum condition; for the inducing force is divided like the attractive force. Hence certain machines in which several kinds of inductions are combined do not yield more than others in which only one kind of induction is in action.

VARIOUS MAGNETO-ELECTRIC GENERATORS OF ELECTRIC LIGHT.

In *tomes II. and V.* of my *Exposé des applications de l'électricité* I have given a nearly complete history of the various induction generators that have been invented; but as we have now to consider only machines for light, only those generators which have yielded the most important results will occupy our attention, and these are:—1°, the machines of the *Alliance Co.*; 2°, the dynamo-electric machines of Wilde, Ladd, Wallace Farmer, Siemens, Lontin, &c.; 3°, the electro-magnetic machines with rings of Gramme, De Méritens, Brush, and Bürgin; 4°, the divided current machines of

Lontin, Gramme, Siemens, &c. We shall of course begin with the *Alliance* machines, the earliest of all

The Alliance Machines.—The comparatively powerful effects produced by the magneto-electric machines of Pixii and of Clarke at once suggested the idea of using them as economical generators of electricity, and it was supposed that by making them of a large size and driving them with a steam-engine, not only might the cost of electricity, which is so great with batteries, be considerably reduced, but currents of much greater regularity and constancy might be obtained. By the year 1849 Nollet, professor of physics in the military school at Brussels, proposed in fact to construct a Clarke's machine on a large scale, and by introducing into it the improvements which the progress of science and his own experiments had suggested, he invented the machine which is now known as the *Alliance Machine*. Unfortunately his labours were arrested by death, when he was about to see his scheme, not indeed successful, for its success was not to be immediate, but to see it submitted to practical tests. Bold speculators, helped by rich and powerful persons, succeeded indeed in floating a scheme, founded on Nollet's machines, for extracting gas from water. This was a mad notion, but for that very reason it found adherents, and it was the Company then formed which, under the name of *The Alliance*, set up by the year 1855, in buildings belonging to the *Hôtel des Invalides*, the first large magneto-electric machines known in Europe. Of course the results obtained were miserable, to say the least, and in 1856 the Company was compelled to go into liquidation.

It was reorganized some time afterwards, and having appointed Berlioz as its manager, it endeavoured to profit by the considerable materials it had formed. I was then consulted, and indicated to Berlioz the application which he could make of them to the electric light and to electroplating. But for that purpose many improvements had to

be introduced into these machines, and all the electricians of the time contributed each a stone to the edifice.

Among these improvements there is one by which double the effect is at once obtained. It was suggested by Masson, at that time professor of natural philosophy at the *École Centrale*, whom I took to see these machines, and consisted in the suppression of the commutator formerly used in all such machines. All these improvements, which were admirably carried out by Van Malderen, the Company's engineer, made it possible, in conjunction with the improvements he himself introduced, to carry the machines to a degree of perfection which the most sanguine had scarcely hoped for, and which it was thought could not be surpassed. And then, for the first time, attention was turned to the availability of the electric light for the illumination of ships and lighthouses. In conjunction with Reynaud and Degrand, experiments were thereupon instituted, and shortly afterwards, in 1863, it was found possible to illuminate the lighthouses of *La Hève* in this way.

About the same time experiments were made regarding the use of the electric light for ships. These experiments did not at first prove entirely successful, owing chiefly to the opposition of the navy. But after a while the importance of the results obtained came to be understood. France thus led the van in this double path of progress, as she still does in the matter of public illumination; but we must point out that the civilized world is indebted to the *Alliance* Company, and to the enterprise of its intelligent manager Berlioz, for these beautiful applications of electricity.

Now that we have acknowledged our obligations to a Company whose efforts fortune failed to reward, we are going to study the constructive details of their machines.

The principle of the *Alliance* Company's machine much resembles that on which Clarke's machine is based, but the mechanical arrangement is so contrived that the induction coils and magnets may be multiplied without inconvenience.

Sixteen coils are placed on a bronze wheel provided with suitable receptacles and fastening-collars by which they are strongly clasped. This arrangement, which for brevity we shall call the *disc*, revolves between two rows of horseshoe magnets, fixed parallel to the plane of the disc on a particular kind of frame constructed of wood only, at least in the vicinity of the magnets. Each row contains eight magnets, and thus presents sixteen poles at uniform distances apart. Thus there are as many poles as coils, and when any one of the latter is opposite a pole the remaining fifteen are in a like position.

One machine may have several discs mounted on the same axle, with several rows of magnets fixed on the same frame. The number of discs does not usually exceed six, as the machines would be too long, and it would be difficult to avoid flexure of the axle and the frame. It should be borne in mind that the coils must revolve as close as possible to the magnets, but without touching them. At the present time nearly all these machines have only four discs.

Fig. 15 shows a general view of a six-disc machine, and Fig. 16 indicates the manner in which each coil *E* is presented before the poles *A, B; B'', A''; a, b; b', a', &c.*, of the different magnets, which are so placed in the contiguous rows that a north pole may be opposite to a south pole in order to polarize in opposite directions the magnetic core of each coil. The ends of the wires of the coils are attached to flat pieces of wood fixed on the bronze wheel, and on these the coils may be arranged either for tension or for quantity, like the elements of an hydro-electric battery. One pole of the total current is connected with the axle *c*, which communicates with the frame through the bearings; the other pole ends in a metallic collar, *D C*, concentric with the axle, and insulated from it by wood or ebonite, and these two poles are connected with the external circuit by the cast-iron frame of the apparatus, and by a friction-spring which, by means of a wire, is in communication with a binding screw.

We shall now enter into some details of the parts of these machines.

The magnets are, as we have said, of a horseshoe form,

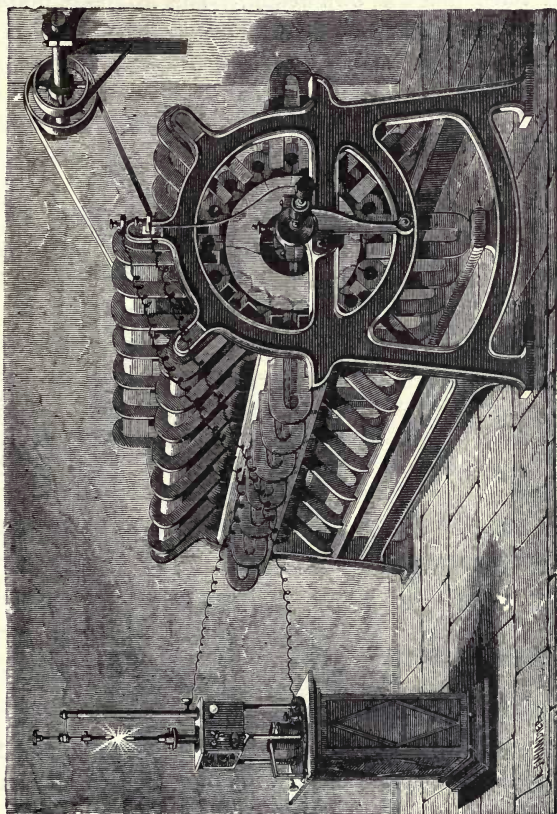


FIG. 15.

and come from the workshops of Allevard ; they weigh about 20 kilogrammes each, and are composed of five or six plates of tempered steel, fitted to each other by grinding, and held together by screws ; the thickness of each plate is about

1 centimetre. For the sake of perfect uniformity of thickness at their polar extremities, and also for readiness of adjustment, they are provided with soft iron poles. Each plate is magnetized by the ordinary process, and the bundle should support three times its own weight. This magnetization is, moreover, improved rather than otherwise by the action of the machine.

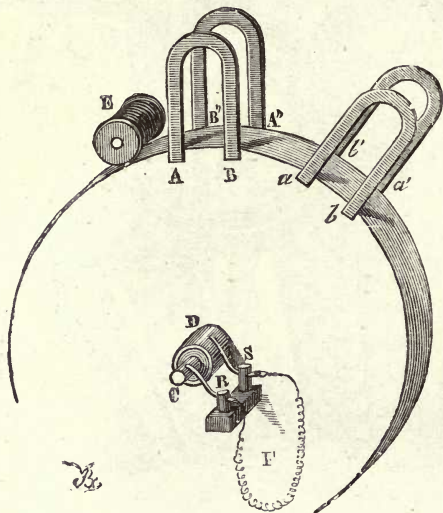


FIG. 16.

The bobbins have undergone many alterations; at the present time they are formed of iron tubes split longitudinally, and have brass caps also divided in order to diminish disadvantageous induction. They are 10 centimetres long and 4 centimetres in diameter, and there are two tubes—one within the other.

The length and action of the wires of these bobbins should depend, as will be readily understood, on the resistance of the external circuit, on the number of bobbins, and on the

kind of work required. Nevertheless, experience has shown that in the use of the machine for the electric light, the best results have been yielded with bundles containing eight insulated wires, each 1 millimetre in diameter, 30 metres long, and joined eight together. These wires are covered with a layer of cotton impregnated with a solution of Judea bitumen in spirits of turpentine, or in benzine. This kind of varnish has the advantage of drying very quickly, and not easily cracking; it is besides very thin, so that it does not materially increase the thickness of the different layers of spires.

According to the experiments of Jamin and Roger, the electro-motive force of the current sent from a six-disc *Alliance* machine, with the coils arranged for tension, and with a velocity of rotation of 200 turns per minute, is equivalent to 226 Bunsen cells; but when the coils are arranged for quantity the electro-motive force is equivalent to only 38 Bunsen cells. The resistance of the generator was equivalent to that of 655 Bunsen cells in the first case, and to 18 in the second case. The light yielded may be nearly represented by that of 230 Carcel lamps, and the cost of the current producing it would be, according to the calculations of Reynaud, the inspector of lighthouses, 1 fr. 10 c. per hour. But since these experiments were made great improvements have been effected in the machines, and we shall presently give the figures representing their performance and their cost; here we shall merely state as the net result that the ordinary *Alliance* machines with four discs are able, with a speed of 400 turns per minute, to maintain 3 Jablochkoff electric candles. Under exceptional circumstances this yield has even been very much increased, and machines have been spoken of capable of supplying 6 candles, but the ordinary machines are far from giving such a result.

Some time after the definite establishment of the machines we are speaking of, Holmes, a former *employé* of the *Alliance* Company, made in England machines of the same kind,

but of larger dimensions, which however yielded results inferior to those just mentioned. Nevertheless, they were fitted up for the illumination of lighthouses on the English coast. It will be seen farther on by the trials made in England itself that of all the machines tried these gave the least advantageous results, and we shall, therefore, say nothing more about them.

Wilde's Machine.—Soft iron being, by reason of its greater magnetic conductivity, capable of giving a much greater maximum magnetization than the tempered steel of which permanent magnets are formed, Wilde thought that there might be an advantage in employing as inducing organs electro-magnets instead of magnets, and that a small supplementary magneto-electric machine, actuated by the same motion as the induction machine proper, might be used to magnetize them. Reasoning in this way, he was led to the machine represented in Fig. 17, which was the starting-point for all the machines subsequently designated dynamo-electric machines.

We shall, in fact, soon see that this small supplementary or priming machine was unnecessary, provided the whole or a part of the induced current were made to traverse the wire of the electro-magnets. Nevertheless, Wilde's machine produced very good results, and it was the first machine of small dimensions which was able to generate the electric light; but unfortunately it required a great speed of rotation.

As shown in Fig. 17, this machine is composed of two parts, of which the upper one is in a manner a miniature copy of the other. The former is a Siemens' magneto-electric machine, with a magnet *M* of 16 plates, between whose poles, *m n*, turns a Siemens' bobbin *o*, already described on page 57. This small machine is placed upon an iron stage *p*, which serves as a connecting piece to the branches *A B* of the inducing electro-magnet, formed of iron plates wound round with thick wires, and terminated by the

two polar pieces T T, between which the induction coil turns.

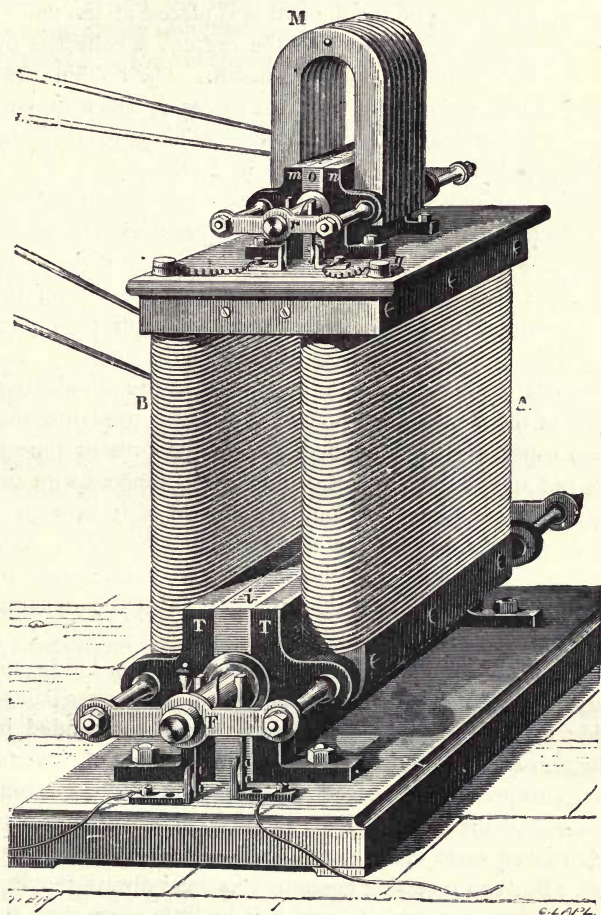


FIG. 17.

As the machine rotates with a speed of from 1,700 to 2,500 revolutions per minute, great heating is thereby occasioned; it was necessary to dispose within the pieces of

copper *i*, which separate the polar pieces T T, a channel through which a current of cold water was made to circulate.

The commutator of the apparatus is placed at the end of the axle of the coil, from which the current is collected by means of two springs pressing against it. The bobbin turns also in bearings placed in the cross pieces R, which support it at its extremities, and suitable lubricating apparatus constantly supply the rubbing surfaces with oil.

Under the influence of the movement given to the magneto-electric machine M, the induced current excited in the armature *o* presents itself at the two binding screws *p q*, which are connected with the two ends of the wire of the electro-magnet A B, and the bobbin turning in F supplies the induced currents required to produce the light.

Although this machine has been used in the illumination of one of the Scottish lighthouses, it is to electroplating that it has especially been applied, and at the present time it does not appear to us that it could have competed with any of the new machines. A long description of it is given in our *Exposé des applications de l'électricité tome II.*, p. 226.

Of course the bobbin of the magneto-electric machine revolves with a less velocity than the bobbin of the dynamo-electric machine.

In another arrangement of a machine of this kind—less generally known, doubtless, on account of its greater bulk—Wilde mounted a series of magnetic cores, surrounded by induction coils, on an iron disc revolving in front of powerful electro-magnets; and instead of a second induction machine set apart for the excitation of the inducing electro-magnets, he borrowed some of its own coils from the induced system itself. But two reversing commutators were always required to rectify the two currents, and it is by little more than the suppression of these commutators that the Wallace Farmer and Lontin machines, which we shall presently study, are distinguished from Wilde's. It is curious that this machine did not at once attract more attention, and that it should be

Ladd who benefited, in reputation at least, by the novelty of this combination. Since the lawsuit brought by Wilde against Ladd, none of the last-named gentleman's machines have been made for illumination, and I am told that the model exhibited in 1867 is the only one that has been shown.

Ladd's Machine.—A short time after the invention of Wilde's first machine, Wheatstone, thinking that by carrying back the effect to its cause, a very minute initial magnetization communicated to an electro-magnet might suffice to increase its power indefinitely, conceived the idea of making the induced current which might be produced circulate through its magnetizing helix, and he was led to suppress the electro-magnetic system in Wilde's machine, and to replace it by the momentary action of a very feeble voltaic battery. This battery gave rise to an initial magnetization in the inducing electro-magnet, and leaving in it a certain amount of condensed or residuary magnetism, supplied the primary cause of the disengagement of electricity which was required for more energetic action. From this arrangement resulted then a successive increment of the power of the inducing electro-magnet, and consequently a strengthening of the induction current, which could have no other limit than the maximum saturation of the electro-magnet and the mechanical resistance offered to the motion of the machine. This idea, developed in detail by Wheatstone in a paper read before the Royal Society of London on the 14th February, 1867, was not long in being improved upon by Siemens and Ladd, the former of whom conceived the idea of suppressing the priming battery used by Wheatstone for putting his apparatus into action, seeing that the mere residual magnetism of the iron or the action of terrestrial magnetism would suffice to bring about the first induction. Ladd adopted the plan of dividing the inductive effect between two different circuits. The induction was therefore simultaneously effected in two different coils; the current pro-

duced in one of the coils was used to successively augment the power of the inducing electro-magnet, while the other coil was utilized for the external work. This combination, however, was, as we have seen, the same as Wilde's. It was at first expected that great advantages would result from this arrangement, especially as regards the electric light, for it was supposed that a working current so variable in its intensity would, in consequence of passing completely through the inducing electro-magnet, increase the effects of the variations in the ratio of the simple power to the square, since the electro-magnetic forces are proportional to the squares of the intensities of the current. But numerous experiments since made by Gramme and Lontin showed that there was infinitely more advantage gained by causing the whole induced current to traverse the inducing electro-magnet; so that at the present day the original arrangement of Siemens has been reverted to, and what is still more curious, a rather lively controversy regarding this matter has been carried on by Lontin, who thinks he discovered this kind of action.*

Be that as it may, Ladd's machine was in 1867 regarded as one of the wonders of the Exhibition, and the small dimensions of the apparatus were specially a matter for surprise. At that period people were accustomed to the large machines of Holmes and of the *Alliance Co.*, and a machine of 70 to 80 centimetres in length, 35 or 40 in breadth, and 20 or 30 in depth, capable of producing a relatively intense electric light, was really a matter for astonishment. Nevertheless, the great velocity of rotation that had to be given to the machine, and the large quantity of heat it generated, soon showed that the problem of the economical production of the electric light was far from having been solved in this way. But the principle of the dynamo-electric system was regarded as in itself an advance, and we shall see that the

* It would appear that Siemens had invented his apparatus simultaneously with Wheatstone, and had announced it to the Royal Society of London on the same day.

machines of Gramme, of Lontin, of Brush, of Bürgin, and of Wallace Farmer have all availed themselves of it.

Ladd's machine, represented in Fig. 18, was in a manner merely one of Wilde's machines turned horizontally, with its upper part replaced by a second system, having a rotating bobbin similar to that of the lower part. The inducing

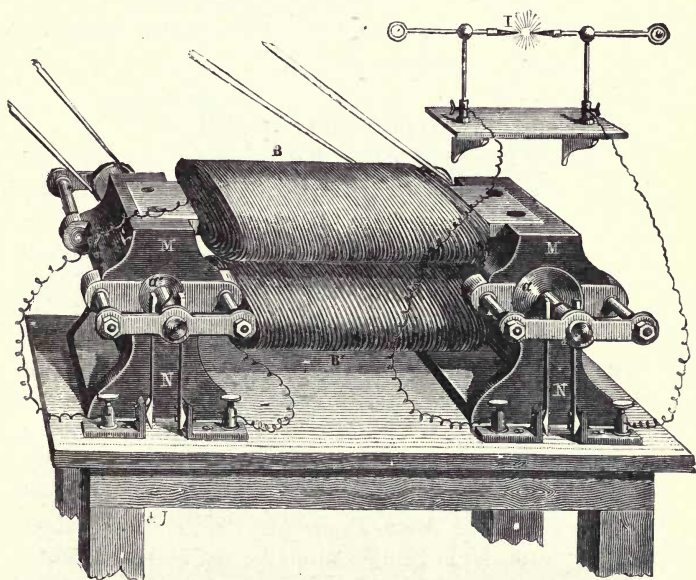


FIG. 18.

system was therefore represented by the two flat horizontal coils $B B'$, and the induced armatures were placed at the ends $a a'$, inside of the two iron standards $N M$, $M N$, composed of two parts forming the polar armatures of the magnetic coils $B B'$. One of the bobbins a , less than the other, was intended to excite the inducing electro-magnet; and the other bobbin a' supplied the current for the light. These currents were collected, as in Wilde's machine, by means of the springs shown in the figure.

In order that the arrangement might utilize the more powerful effects of the electro-magnet when it acts like a horseshoe magnet, and that the inducing force might not be divided, the two armatures were arranged in such a manner that when the iron parts of the bobbin α were opposite the polar armatures, the same parts of the bobbin α' were in a perpendicular position, and therefore in that position in which, leaving the polar armatures which had acted on them, the direct induced currents were produced.

Of course the two bobbins were set in motion by two belts passing over the same drum.

With the machine of the small dimensions, shown at the Exhibition of 1867, the current transmitted externally was equivalent to that from 25 or 30 Bunsen cells. It was able as we have already stated, to supply—somewhat discontinuously, it is true—one of Foucault's medium-sized electric light regulators.

Gramme's Machine.—The Gramme machine, of which so much has lately been heard, and which has produced the most remarkable results, was originally contrived, so far at least as its general arrangement goes, by Paccinotti, of Pisa, and Worms, of Romilly, as is proved by a description published by the former in the *Nuovo Cimento* for 1860, and by a patent taken out by the latter gentleman on the 3rd March, 1866.*

It was, in fact, only in 1870 that the Gramme machine was constructed; but the principle of the combination of currents in this machine was quite different from that employed in the two which preceded it, and it is for this reason that the one has given unlooked-for results, while the others have remained in the state of ordinary machines. We shall here, therefore, concern ourselves with only the Gramme machine, which is besides the best known at the present day of all dynamo-electric machines.

* See the description of this machine in my *Exposé des applications de l'électricité*, t. II., p. 222.

Like most important machines, the Gramme machine has since its first invention undergone many transformations, and at the present day it is still constructed in several forms, adapted for special applications; but as we have here to consider only apparatus for light, we shall describe only the form most commonly used, which is represented in Fig. 19.

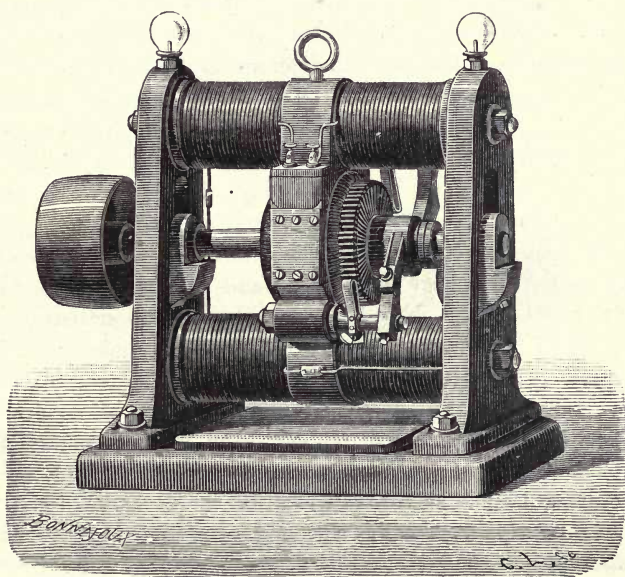


FIG. 19.

This machine is based upon the effects described on page 53, resulting from the successive reversing of the polarity of a magnetic body passing rapidly before an inducing magnet, and particularly from the induced currents which are produced on the passage of the spires of an induced coil before the same inducing magnet. In order to obtain these effects continuously the electro-magnetic elements must be arranged in such a manner that the inducing action shall never be in-

interrupted, and this led to their arrangement in a circle. Therefore an iron ring was used, surrounded transversely by a coil which completely covered it, and subjected to the action of an inducing magnet, simply magnetic at first, but afterwards electro-magnetic. According to the effects explained on page 54, continuous currents should be obtained without a commutator, their direction depending on the rotatory movement. But it was soon noticed that opposing actions were produced, and this led to the division of the coil surrounding the ring into different sections, so that these might be combined like the cells of a battery, and that the poles of a powerful inducing electro-magnet might be made to act upon them. Under these conditions it was, in fact possible to place on the connecting wires of the several sections of the coil, derivation wires communicating with plates arranged round a circular drum, on which pressed two springs to collect the current, and these springs, being in this way placed in the position of a derivation between two equal generators joined by their similar poles, would transmit the current into the circuit without the necessity of any inversions, and therefore without the use of commutators. This was a very happy idea, and in it is contained the essence of Gramme's invention. We shall presently see that it has been applied to nearly all the new dynamo-electric machines with continuous currents, a fact which proves its importance.

The effects produced in the Gramme invention are, however, somewhat complex, and are connected with several causes, the principal of which, as we have seen, is the action of the magnetic poles on the several spires of the induced coil; but this action is itself double, for it may result from the passage of the coils before these poles, as well as from an action analagous to a displacement of these along a ring differently polarized in its different points. Let us first study the former effect, referring to Fig. 20, which theoretically represents the outline of a Gramme machine, and let us sup-

pose for a moment that there is a wooden ring instead of the iron one. When one of the coils, *E*, approaches the pole *S*, turning from right to left, a current will be developed which, according to the law enunciated on page 54, will be *direct*. If the movement, instead of being continued, were to take place backward, there would still, according to the same law, be a new current which would be inverse, and therefore in the opposite direction to the first; but if the movement is continued in the same direction this will not occur, for when the coil *E* has passed the point *S* the pole will act on it at its

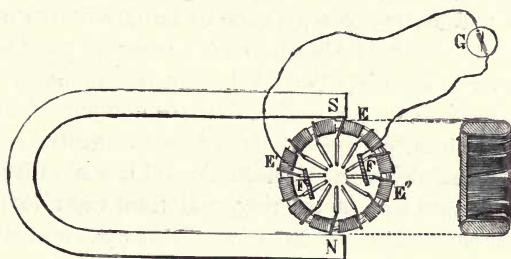


FIG. 20.

opposite end; so that instead of a current in the opposite direction there will be a current in the same direction, which will go on decreasing until *E'* is reached; at this time the coil will be approaching the pole *N*, but this acting on the front end of the coil will create a current having the opposite direction to those produced in the coil on approaching *S*, because this pole is of opposite name. After having passed *N*, the travelling coil will be influenced by *N* at its hinder extremity, and a new current in the same direction as the last will be produced, until *E''* is reached, when the direct currents will again show themselves. These effects are produced in all the coils, those occupying the upper part of the ring being at a given moment traversed by currents in a direction varying according to the winding of the coil and the direction of the movement; and the coils occupying the

lower part are traversed by currents in precisely the opposite direction; but as at the two points where the junction of these two opposite currents take place the circuit has a derivation by means of the rubbing pieces F and F', connected with the external circuit, they flow through this derivation united in quantity.

Let us now examine what happens from the motion of these coils with regard to the magnetism developed in the ring, and in order to fix our ideas, we shall suppose that only one annular electro-magnet turning between the two poles N S of an iron horseshoe magnet is magnetized in such a manner that the system appears to be constituted of two semicircular magnets joined to each other by their similar poles, whence it follows that on the equatorial line, that is to say, on the diameter perpendicular to the line joining the two poles of the inducing magnet, there exist two neutral regions, and it follows also that the magnetic coil is wound from left to right in one side of the ring, and from right to left in the other side. Now let us see what takes place when coils of a short length, such as those previously referred to, are made to move before such a magnetic system, and let us follow, as before, the course of the short coil E, supposing the iron ring to be stationary. In leaving the neutral line on the right to move towards the point S, the coil will be receding from the *resultant* of all the magnetic spires of the right part of the ring corresponding with its neutral line, and there will be developed in it a *direct* current, as in the case in which, without a magnet ring, it is made to approach the pole S. When it has passed the upper part of the ring, it will approach the *resultant* of the magnetic spires of the left part of that ring, and give rise to an inverse current; but on account of the different direction of its winding, this current will traverse the circuit in the same direction as the first current, and it will be only at the neutral line towards the left that these effects will change. The coil will then be found to undergo the same reactions as those we have before

studied. We shall thus have two currents superposed, and to these will be united the currents resulting from the inversions of the polarities, for these constant polarities which we have supposed in the ring do not exist, inasmuch as it turns with the coils, and a stable distribution can be maintained in the system only by the continual inversion of the polarities at the different points of the ring. It will be seen that the resulting current must therefore be in the same direction as those produced by the direct action of the magnetic poles, for they are of the same nature as those which would result from the displacement of the magnetic poles themselves, and they must be *direct* for the advancing coils, and *inverse* for the retiring; but as these last are presented to the inducing poles in the inverse manner, the definitive effect is produced in the same direction.

It has been supposed that, in the Gramme machine, the iron ring performed other functions, perhaps more important than those we have just analysed. Thus several physicists state that it may prevent injurious inductions by acting as a screen to the action of the inducing magnet on the portions of the coils opposite to it. On the other hand, it is thought that by acting as an armature to the magnetic poles, it considerably heightens their energy and concentrates the action. Although there may be some truth in these assertions, we do not see that the advantages of the iron ring are so important, since the Siemens machine, which is not provided with it, gives considerable effects.

As iron is susceptible of a magnetization much greater than that which can be preserved by tempered steel, and as the power of electro-magnets is infinitely more energetic than that of permanent magnets, Gramme has combined his schemes of annular induction coil with a Ladd's electro-magnetic system, in which Siemens' armature is suppressed, and in order to give more power to this arrangement he has formed the electro-magnetic system with a double set of electro-magnets, the branches of which are opposed to each

by their similar poles. There results in the middle of the system two consequent poles of great power, and it is between these poles, prolonged and curved, that the ring is enclosed, with its axle carrying the current-collectors as seen in Fig. 19.

In the first Gramme machines two rings were used, one being reserved, as in Ladd's system, to excite the electro-magnet. But, as we have already said, this ring had soon to be suppressed, and the induced current in its entirety

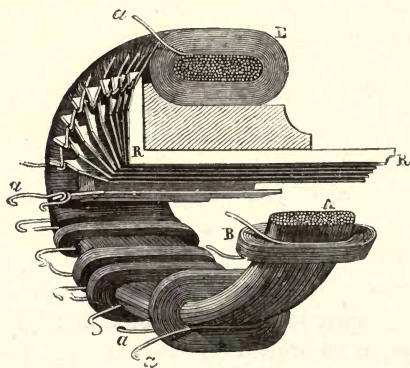


FIG. 21.

was made to pass through the electro-magnetic system, by which the effects were considerably increased. Henceforth the machines had but a single ring, but it was made of a large size, and, as shown in Fig. 21, the ring itself, instead of being made of a solid piece of iron, was formed by a bundle of many iron wires, as in the voltaic induction machines.

Fig. 21 represents a section of this ring, and shows the way in which the different sections of the induced coil are wound upon it. The connecting wires *a a a* of the various sections are, as shown in the upper part of the figure, soldered to the plates *R R*, which are placed side by side round the axle of rotation, and constitute a kind of drum on which

press the two springs of the collector, which are formed by a sort of brush of metallic wires held by supports, as may be observed on the right of the ring in Fig. 19. These plates are, of course, separated by layers of ebonite in order to insulate them electrically. In the figure the inducing electro-magnets are placed horizontally at the top and bottom of the machine, and their polar expansions are seen in the metallic pieces surrounding the ring, serving at the same time as supports to the stems of the rubbing pieces and to the binding screws of the induced circuit.

Gramme machines of the last pattern are little more than 65 centimetres long, 41 centimetres wide, and 50 centimetres high; they weigh 175 kilogrammes, and with $2\frac{1}{2}$ horse-power, giving a speed of revolution of 850 turns per minute, they yield an electric light equal to 2,500 candles or 270 Carcel lamps.

We shall presently see that Gramme has constructed another system of machines to supply currents alternately reversed, and so arranged that the action of the machine may be divided and made to yield currents in several distinct circuits. This arrangement enabled the illumination of the *Avenue de l'Opéra* by Jablochhoff candles to be carried out.

We shall not speak of other forms of the Gramme machine except in the chapter on the applications of the electric light. All the necessary details as regards these may, however, be found in Fontaine's work, entitled *L'Éclairage à l'électricité*.

Schuckert has somewhat modified the Gramme machine by employing a flat ring, and by utilizing the magnetism of the electro-magnets on the lateral faces of the ring, instead of on the cylindrical part; but we are not sure that the alleged increase of power which has been attributed to this arrangement is real, and the machine appears to us merely a copy of the French invention.

We may say the same of a machine constructed by Rapieff, in which the ring is so arranged to be subjected to induction

inside as well as outside; but this machine produces alternately reversed currents.

Siemens' Machine. — The machine of Siemens and Hafner-Alteneck, represented in Fig. 22, which has in comparative experiments made in England furnished the best results, is founded on nearly the same principle as that of

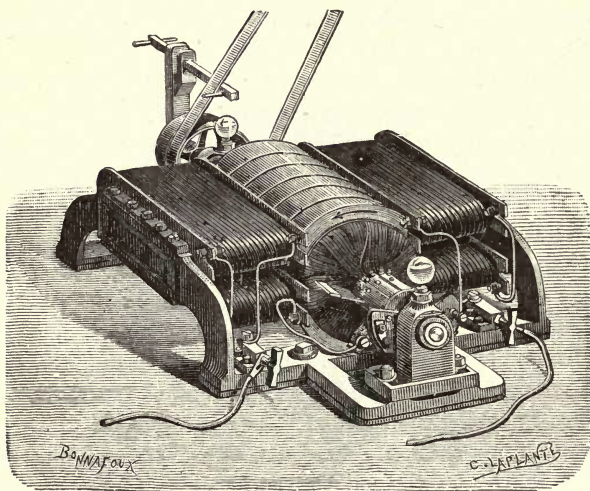


FIG. 22.

Gramme, although at first sight it appears to be merely a modification of the elongated coil system of Siemens, that we have already seen taken advantage of in the machines of Wilde and of Ladd. In this new system the cylindrical coil for receiving the induction is of large diameter, and is formed of a revolving cylinder of copper, on which, parallel to its axis, are wound a certain number of juxtaposed coils like the coils of a galvanometer. These coils are connected for tension, but metallic plates join with their connecting wire to a series of plates arranged round a drum of insulating substance, fixed

on the same axle as the cylinder; and against these, as in the Gramme machine, there press two rubbers of metallic wires, which transmit the current supplied by the machine. This cylinder is surrounded by the expanded poles of a dynamo-electric system through which the entire induced current is passed, and these semicircular poles are divided by a certain number of slits in order to facilitate the demagnetizations. The branches of the electro-magnets are also formed by plates of iron wider than they are long, joined two by two by pieces of iron, which serve as a frame to the apparatus and form its pillow-blocks.

Finally, inside of the copper cylinder is placed, opposite the poles of the inducing magnet, an iron framework, terminated by arched plates of the same metal, which by forming a kind of armature for the inducing electro-magnets, considerably reinforce their power.

Under these conditions the induced currents are due to the dynamical action which we have explained on page 77, that is to say, to the movement of the galvanometrical coils before the inducing poles, only, the two poles of the magnet act simultaneously on each coil; and as this double action takes place on the opposite parts of these coils, where the current has necessarily a contrary direction in relation to the axis of figure, the two effects concur in the same result. The change of direction in the currents is, however, produced in the same manner as in the Gramme machine, in the centre of the interpolar space, and it is there that the two rubbers of the collector are applied. It will easily be understood that currents of polar inversion count for nothing in this machine, and, as I have said, the iron framework acts merely by reinforcing the electro-magnetic action. Therefore, if necessary, it may be dispensed with; and this especially distinguishes this system from that of Gramme, since in the latter the iron ring, besides being useful for effective inductive action, serves as a framework for the support of the coils.

In the machine we are now speaking of, the brush rubbers, which act as collectors for the induced current, are carried on a kind of balance, which by a mere inclination in one direction or the other and by a change of the wires allows the induced currents to be obtained in either direction at pleasure.

Siemens has recently arranged a new form of this machine, of much smaller dimensions than the preceding, resembling the induction machines of the physical laboratory. This is the form which sets in action the machines by the same maker for reversing the currents, that we shall describe farther on, and in which it is not easy to understand how so small a machine can produce effects so powerful.

The arrangement of the apparatus represented in Fig. 23 is nearly the same as that we have just described, except that the system is placed vertically instead of horizontally, and the induced coil, instead of being provided inside with a framework of iron serving as armature to the electro-magnetic system, is provided with a cylinder formed of a bundle of wires, like the cores of voltaic induction machines. These wires, while acting as an armature, at the same time increase the intensity of the inductive effects, as in the machines of Ruhmkorff and others.

These machines require, however, a high speed of rotation, from 1,100 to 1,375 turns per minute ; but it does not appear that they heat much. The current they supply is sufficiently powerful to light 16 Jablochkoff candles by passing through a machine of the form of Fig. 35 for dividing and reversing the currents.

Siemens has also constructed a form of magneto-electric machine arranged nearly under the same conditions as the preceding, and differing from them only that instead of inducing electro-magnets there are bundles of magnetized bars separated from each, and bound together by strong iron frames as broad as the length of the induced coil. The machine has also a commutator with four rubbers.

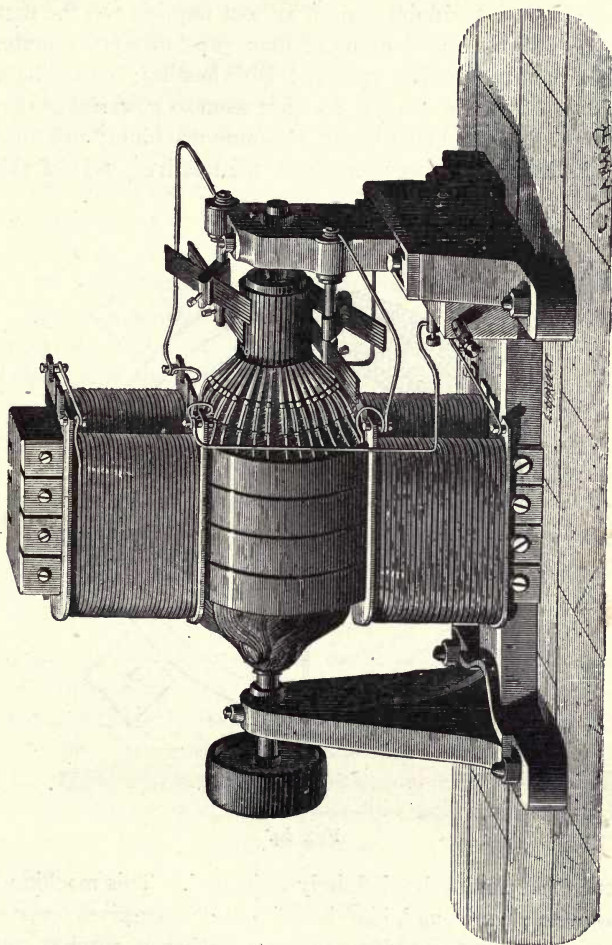


FIG. 23.

De Méritens' Machine.—To judge by the number of electric candles lighted by this machine, it might be thought the most powerful magneto-electric generator with a given motive force. It can, in fact, with a motive force not exceeding 1 horse-power, maintain 3 Jablochkoff candles

lighted for an indefinite period, without requiring on the part of the motor a speed of more than 700 turns per minute, and without producing any appreciable heating; but the light furnished by these candles does not seem so powerful as that of the candles supplied by the Gramme machines; and until precise measures have been given, the relative power of this

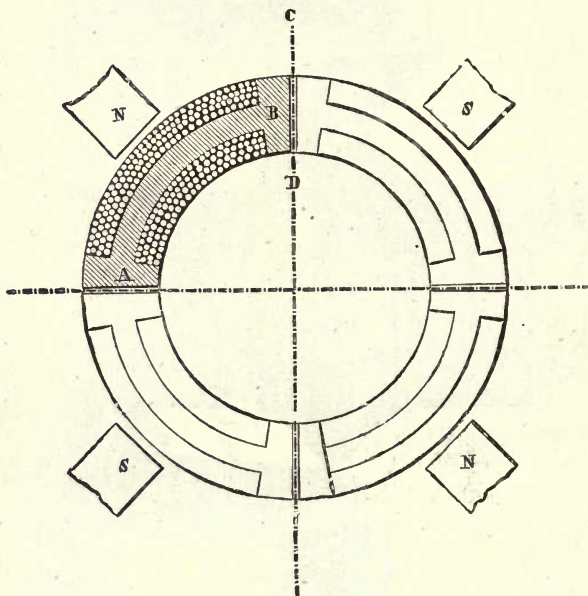


FIG. 24.

generator cannot be definitely estimated. This machine is magneto electric, and, like that of the Alliance, gives reversed currents; but to produce the same effect it requires only 8 Allevard magnets instead of 48, and only a quarter of the motive power. Such, at least, is De Méritens' statement.*

The advantageous effects of this kind of machine result from the fact that the induction currents produced in the

* The truth is this machine requires $1\frac{1}{4}$ horse-power.

ring of the Gramme machines are added to those produced in the ordinary magneto-electric machines.

In order that it may be understood, let us imagine a Gramme ring (Fig. 24) divided, for example, into four sections, magnetically insulated from each other, and therefore forming four curved electro-magnets placed end to end. Let us imagine that the iron core of each of these sections is terminated at its two extremities by a piece of iron, A B, forming an expansion of its poles; and let us suppose that all these pieces, connected by means of a piece of copper, C D, constitute a solid ring, round which are placed the permanent magnets, N S N S, with their poles alternating. Let us examine what will happen when this ring completes a rotary movement on itself; and let us first observe the effect that will result, for example, from the approach of the expanded pole B, as when moving from left to right it approaches N. At this moment there will be developed in the electro-magnetic coil of A B an induced current of magnetization, as in Clarke's machine. This current will be instantaneous, and in the reverse direction from Ampère's particular currents of the inducing magnet. It will be very energetic, on account of the nearness of B to the pole N; but the ring in advancing sets up between the pole N and the core A B a series of magnetic displacements which will give rise to a set of currents of reversed polarity showing themselves from B to A. These currents will be direct, as compared with the particular current of N, but they are not instantaneous, and go on increasing in energy from B to A. To these are at the same time united the currents of dynamical induction resulting from the passage of the spires of the coil before the pole N. When A leaves N a current of demagnetization is produced equal in strength to, and in the same direction as, the induction current resulting from the approach of the expansion B to the pole N. The effect is, in fact, then produced at the other end of the magnetic core, and the coil is presented to the inductive action in the reverse way. There

are then, inverse induced currents by the fact of the approach and withdrawal of the expansions B and A, direct induced currents during the passage of the length of core A B before

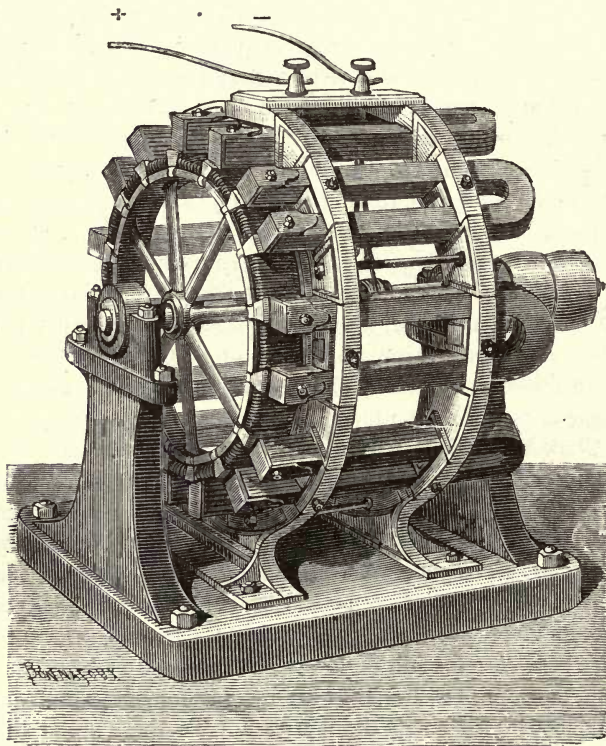


FIG. 25.

the magnetic pole, and direct induced currents resulting from the passage of the spires before N. All the causes of induction are therefore united in this combination.

It will be observed that the action which we have just studied in a single section of the ring may take place simultaneously in all the others, and that there are also added

currents resulting from the lateral reaction of the poles A and B on the neighbouring poles.

In order to increase the inductive effects, De Méritens forms the core A B and its adjuncts A and B of thin plates of iron, cut by the punching machine, as shown on the figure, and bound together in a bundle to the number of fifty, each having a thickness of 1 millimetre. The wires of the coils are, moreover, connected in such a manner that the induced

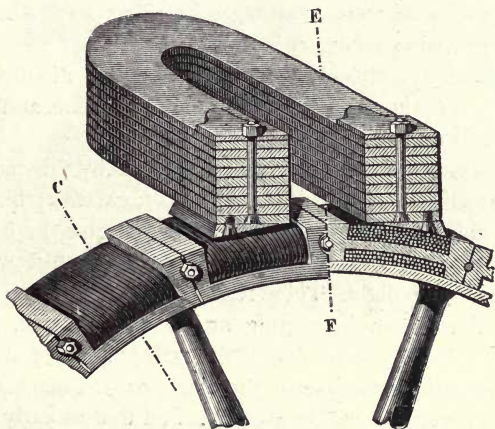


FIG. 26.

currents may be joined for tension, for quantity, or in a series, according to the conditions of their application.

We have in the theoretical figure supposed that only four sections are given, but in reality there are a greater number, and in the form of the machine referred to (shown in Fig. 25) sixteen may be observed. These are mounted on a bronze wheel turning on the axle of the motor.

Round about this wheel are planted the inducing magnets, firmly fixed on two bronze frameworks, in which they are placed horizontally. Fig. 26 shows the manner in which the several elements are mounted.

By a little consideration of the way in which the induced ring is arranged it will be easily seen that it is placed under the best possible constructive conditions. In fact, as each section is separate, it may be removed without disturbing the rest, and therefore the wire may be wound without any difficulty. Those who are acquainted with the difficulties of winding the wires on the Gramme ring will readily appreciate this advantage. In another way the building up of the core by juxtaposed laminæ, which may be punched out at one stroke, is an enormous advantage, for this system dispenses with the precision necessary in the construction of these rings, which it is always difficult to keep quite round. Finally, there is neither commutator nor collector in the machine, and therefore there is no loss of current.

We have seen that the currents supplied by this machine are able to light three or four Jablochkoff candles; but they are also able to light regulators, and in this case the carbons may be separated to the extent of 5 centimetres without extinguishing the light. These results are certainly important.

According to an interesting article by Demoget, in the journal *La Lumière Électrique* of the 15th July, 1879, it would appear that the principle of the above-named machine was discovered long before De Méritens, and that as early as the year 1872 he had constructed a very similar machine, which was described in a sealed packet deposited at the *Académie des Sciences* at the meeting of the 20th January, 1875, and that this machine had yielded remarkable results. Drawings of the machine are given in the article we are referring to, but on inspecting them it appears to us that the electromagnets of the induced ring were not insulated from each other by non-magnetic substances, and in this consists one of the great advantages of De Méritens' machine.

Wallace Former's Machine.—This machine, not previously known in Europe, suddenly acquired some notoriety in consequence of the panic on the Stock Exchange occa-

sioned by the *soi-disant* wonderful discovery made by Edison, which was to abolish gas and its applications for ever. On this occasion Edison mentioned the famous generating machine of Wallace Farmer, which was to supply torrents

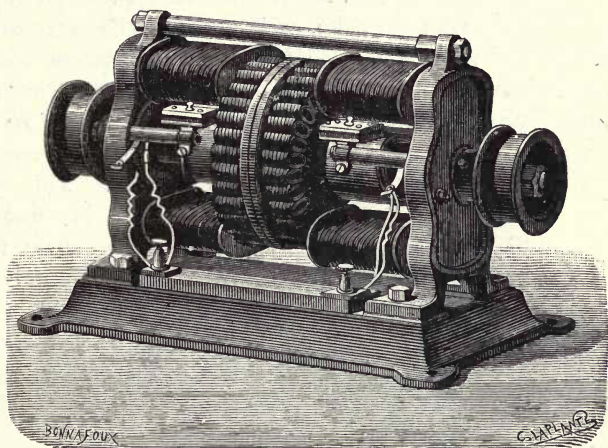


FIG. 27.

of electricity, and everybody was eagerly seeking to learn something of this new wonder. Now, a Report issued by a Committee appointed by the Franklin Institute in America, for a comparative examination of the various machines for light, has quite recently opportunely satisfied the curiosity of the public by giving not only a description of this machine, and of that of Brush, also previously unknown, but also the numerical results of the experiments undertaken by the Committee, and even the verdict of the Committee, who, in spite of the much more favourable results yielded by the Gramme, pronounced in favour of the American machines. We shall, however, have occasion to return to these estimations.

Wallace Farmer's machine, which is represented in Fig. 27, is, in fact, nothing more than a reproduction on a large

scale of Wilde's machine, already spoken of, and of Lontin's machine, which is based on the same principle.

It consists of a large iron disc, provided on both sides with crowns of straight electro-magnets, and turning between the poles of two large electro-magnets with flat branches, having the contrary poles opposite each other. The somewhat flattened coils are connected together for tension on each side of the revolving disc, and the connecting wires are in communication with a collector placed on the axle of rotation, as in the Gramme system, so as to avoid a reversing

commutator. This arrangement, in which there is absolutely no novelty, is shown in Fig. 28.

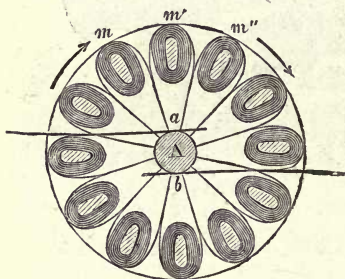


FIG. 28.

It will be perceived that by this arrangement the machine is double, and that each of its parts might act independently; but practically the electrical communi-

cations are so contrived that the currents evolved are united either for quantity or for tension through the whole circuit. The inventor believes that heating effects are avoided by the large uncovered surface presented by the revolving disc; but the Committee pointed out that this advantage is purchased at the expense of the great resistance which the air offers to the motion of the machine; and further, it may be seen by the experiments performed before the Committee that the machine was heated sufficiently to melt sealing-wax.

Brush's Machine.—Brush's machine, represented in Fig. 29, is one of those experimented with by the Committee of the Franklin Institute, and it was, in fact, the one to which the palm of superiority was awarded. In its principle this

machine much resembles that of De Méritens, although it is less skilfully put together, and reminds me of the first attempts made by the last-named gentleman.

This machine consists of a Gramme ring, the coils of which, only eight in number, are separated by rather large intervals, filled up with pieces of iron. This ring revolves vertically between the expanded poles of two oblong horseshoe electro-magnets, having the poles of the same name opposite to each other. In this way the two halves of the ring laterally

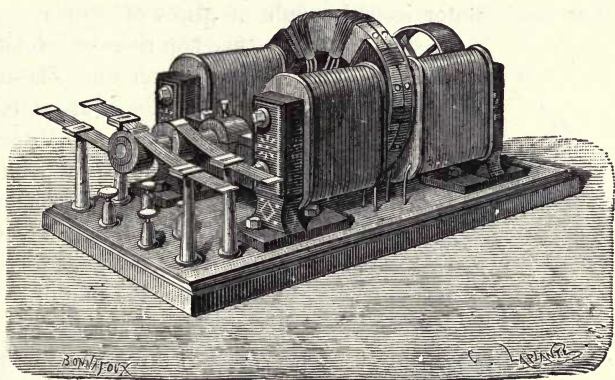


FIG. 29.

surrounded by these poles are polarized uniformly, the one south, the other north; and as with this arrangement alternately reversed currents are produced, as in De Méritens' machines, and as such currents are unsuitable for the magnetization of inducing magnets in dynamo-electric machines, it is necessary to put the coils of the revolving ring in communication with a reversing commutator, for which four rubbers are required. These rubbers, which are shown in the figure to the right and left at the front, are constructed, as in the Gramme machines, of bundles of wires arranged like a brush. Fig. 30 indicates the manner in which the wires of the coils are connected with each other and with the com-

mutator A B. The opposite coils *b d* are, it will be seen, joined end to end, but these connections are shown in the figure for only one pair of coils. In order to place the commutator in a good position, the ends of the wires are made to pass through a hollow axle to reach the projecting parts.

The commutator, A B, is put together in such a manner that three pairs of coils are always in communication with the circuit of the machine, and the remaining pair has its circuit interrupted in the place of the neutral line of the ring.

The commutator itself is made of plates of copper, *a e*, fixed on rings of insulating matter and shaped as in ordinary apparatus of this kind.

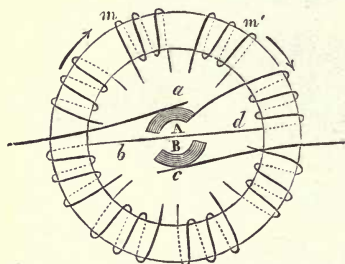


FIG. 30.

The Committee points out that by reason of the iron surfaces which separate the coils being exposed, the ring of this machine is able the more readily to part with its heat, which seldom rises

above 120° Fahrenheit, in spite of its very great velocity of rotation. The machine is blamed, however, for its rather loud noise, which is attributed to the resistance of the air, but which is nothing but the sounds due to the alternations of magnetization and demagnetization in the portions of the ring. These effects are produced also in De Méritens' and in Lontin's machines, and, what is still more curious, the sounds are repeated by the Jablochkoff candles placed in the circuit of these machines. This effect is connected with the electro-telephonic transmissions, which are explained in our work on the telephone.

In another form of the machine there are two commutators corresponding with the two systems formed of the odd

and the even coils. "By this means," says the Report of the Committee, "the circuits may be combined so as to transmit currents of more or less intensity, varying from 55 to 120 volts, or so as to divide the currents between two circuits, each supplying an electric light."

We may point out that, under these circumstances, the Brush machine is inferior to that of De Méritens; 1°, because the iron ring being continuous, the electro-magnetic currents produced by the approach and withdrawal of the magnetic poles lose their energy, as De Méritens proved by his earliest experiments; 2°, because the induced currents gain much when the magnetic cores are formed of very thin pieces of iron bound together in bundles; 3°, because the presence of a reversing commutator occasions much loss of current.

The Brush machine has recently been applied with success to the illumination of the Park, at the city of Cleveland, in America, and if the newspapers of that city may be trusted, it has, in conjunction with the electric lamps of the same inventor, an advantage in economy over the systems tried in England and in France in the proportion of 20 to 5. This machine required only 11 horse-power to supply 12 lights, having the luminous intensity of 200 Carcel lamps. But we believe these accounts are much exaggerated, inasmuch as these 12 lights imply a machine for division, which is not described by the newspapers we allude to, and which would appear to be confounded with that spoken of above.

Bürgin's Machine.—Bürgin, struck like De Méritens with the loss of action in the Gramme ring, resulting from the withdrawal of the iron core from the inducing poles, has sought to cause its approach by making it pass out of the coils at longer or shorter intervals. In order to accomplish this he formed this ring of six separate rings mounted parallel to each other on the same axle, and each having for a magnetic core a square frame of iron wires (Fig. 31) on the sides

of which are wound the induced coils. These coils are wound to the shape of a spindle with a curvature so calculated that the four angular parts of the cores are nearly on a level with the external spires of these different coils, and therefore are able to pass the inducing poles at a very small distance. The frames are also so arranged that the angular and uncovered parts of the cores retire from each other so as to present themselves conformably to a spire of a coil. It follows that the magnetizing actions are produced successively, and that the currents due to these actions, as well as to that

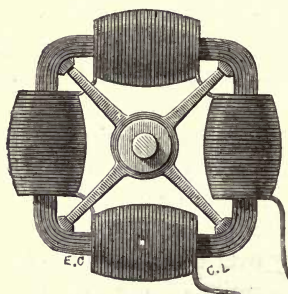


FIG. 31.

between the wires of the coils, are always of the same intensity in the different phases of each revolution of the ring. The induced coils are, moreover, wound in directions alternately reversed, in order to obtain currents in the same direction in each half of the ring. Finally, these coils are joined to a collector exactly in the same way as in Gramme's and in Siemens' machines,

and this arrangement allows continuous currents to be obtained.

The inducer has also the same arrangement as that of the Siemens machines, and the induced current traverses it in its entirety as in those machines.

Experiments made in my presence at Geneva, in the workshops of Turetini, who is the maker of these machines, showed that they have for a given velocity exactly the same luminous power as the ordinary form of Gramme machines, but they have the advantage of becoming very much less heated. In fact, it may be said that they are hardly heated at all. As regards construction, they also present some advantages; thus, for instance, the uncovered parts of the

magnetic cores give the means of fixing the rings on the axis of rotation with precision—a difficult operation with the Gramme ring. In short, this is a very interesting and a very promising machine.

Trouvé's Machine. — Trouvé has also constructed dynamo-electric machines based on nearly the same principle as the preceding machines, but with a reaction of the inducing magnets on the induced, which is effected at the contact of the magnetic pieces, and by a method similar to that which Larmangeat had applied as early as 1855 in his electro-motor with electro-magnets and revolving armatures.

In one of these apparatus the inducer is formed of a large straight electro-magnet, movable horizontally on its axis, and with a core provided with two iron discs, as in the circular electro-magnets of Nicklès. On these discs turn the iron ends of a certain number of bundles of electro-magnets, arranged in a circle, with their poles thus placed successively in contact with the expanded poles of the inducing electro-magnet, and each giving rise to the induction currents, which, reaching a commutator, traverse the inducing coil and supply at once the working and the exciting current. This arrangement is entirely the same as that of Larmangeat's electro-motor.

In another form of the machine, which is now being made on a large scale, the inducing magnet is arranged as we have just mentioned, but it is constituted of two straight electro-magnets placed parallel to each other, and their iron discs are thick enough to have a groove in which move two rings similar to those of the Brush machine, having a common axle of iron, and coils so combined as to give currents rectified by the inducing electro-magnet. Under these conditions the induced and inducing coils form a closed electro-magnetic system in which the movable electro-magnetic pieces are always in contact, and therefore at the maximum of their power.

J. Bellot, the maker of these machines, furnishes us with the following particulars :—

“I have made two small bobbins—one a Gramme, the other with projections on Trouvé’s plan. Each has 20 coils. The Gramme bobbin contains a greater length of wire by 20 per cent. These bobbins are so mounted as to be acted upon by the same electro-magnet, which is wound with a thick wire of a length proportional to the Gramme bobbin. This last is perfectly insulated ; there is no loss between the coils ; but it happens to be otherwise with the former, where some of the coils are in communication with the iron.

“In spite of these disadvantages I obtain a much better result with the coil having projecting pieces.

“The core of the coil, with projections, is made of four sheets of iron, cut and riveted together so as to form a single mass, which was finished on the lathe. This core is wound with 75 metres of wire of 0·65 millimetre diameter. With a velocity of rotation of 1,500 turns per minute I obtain a current equal to that of 8 to 10 Bunsen cells. There is no heating, even when no resistance is interposed in the external circuit.”

Lontin’s Machine.—Lontin’s machine has a special interest for us on account of the complementary machine by which the effect is divided, and which is the first machine of the kind ever invented. As we shall discuss this kind of machine in a separate chapter, we shall here have but a few words to say about the generator properly so called, which is represented in Fig. 32. It consists of a core or iron drum, on which are fixed a large number of iron cores in four rows placed obliquely. These cores are furnished with magnetizing coils, D D D, wound for tension in such a manner that the end of one coil corresponds with the beginning of the next. This system, called by its inventor a magnetic pinion, is mounted on an axle so as to turn between the poles of a powerful electro-magnet with flattened branches, A A, constituting the

inducer, and the coils connected with each other, like the coils of the Gramme machine, are joined by derivation wires with a collector also like that of the Gramme apparatus. Like most of the preceding, this is a dynamo-electric machine,

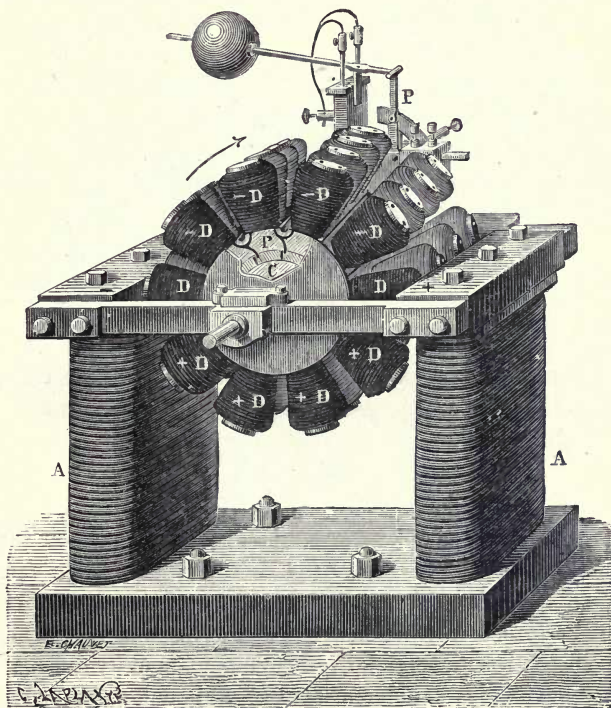


FIG. 32.

and the inducer is excited by the entire induced current. In the most recently constructed form of the machine, some improvements, which we must briefly mention, have been made. In the first place, the polar extremities of the large inducing electro-magnet have been so arranged that the intensity of the induced current can be diminished at will

to any required degree. For this purpose pieces of iron, movable in a kind of groove, have been adapted to the poles, and can be fixed at a greater or less distance from the wires of the magnetic pinion. Secondly, the collector is placed apart from the axis of rotation, so that the machine may be covered up and protected, and in order to accomplish this it was necessary to make the communications through the axis of rotation, and the contacts of the collector have been so arranged as to enclose it on the two sides of the axle under a pressure produced by a counterpoise P. The rubbing parts themselves are made of an alloy of lead and zinc, and fitted to elastic metallic supports.

MACHINES WITH ALTERNATE REVERSIONS OF THE CURRENTS,
ESPECIALLY APPLICABLE TO THE DIVISION OF THE ELECTRIC LIGHT.

For a long time it was a matter for complaint that the generators of the electric light could supply only a very limited number of lights, and the *desideratum* generally required was the construction of a generator capable of furnishing electricity to several derived circuits in quantity sufficient to maintain lights in different places. Although several combinations for solving this problem were long ago proposed, it is only recently that the solution has been accomplished in a satisfactory manner, both as regards the generator and as regards the lights themselves, and we are indebted to Lontin for this important novelty.

Lontin's System.—Lontin's machine for the production of light succeeded not only in dividing the electric light, but

also in so dividing it that the total intensity may be distributed among the several lights as occasion requires.

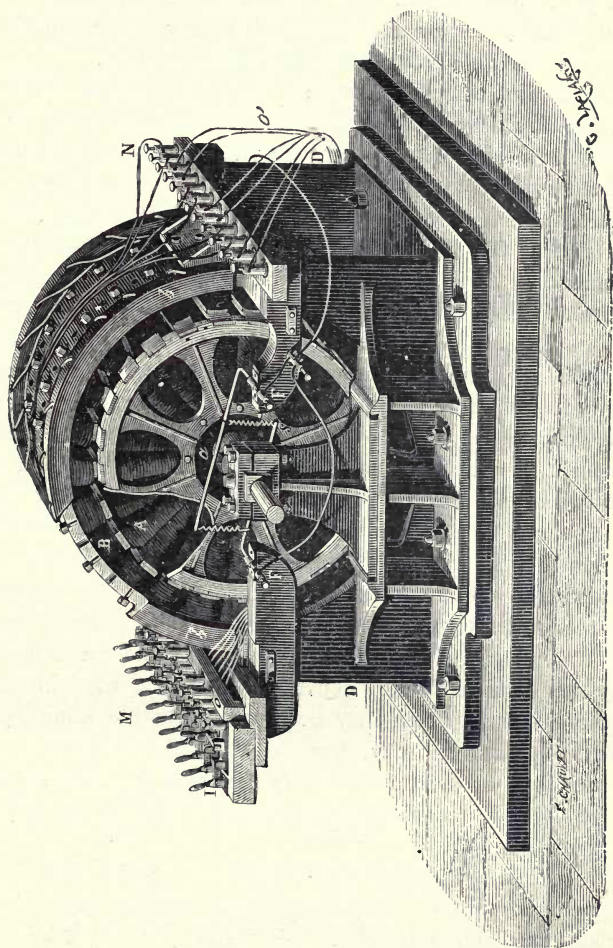


FIG. 33.

In principle this machine consists of a series of electro-magnets, fixed in the interior of an iron crown placed ver-

tically, having in its centre a rotating electro-magnetic system composed of as many magnetic cores as there are electro-magnets on the crown. Fig. 33 shows this machine, in which the rotating interior electro-magnets represent the inducing, and the fixed electro-magnets the induced system.

The inducing system, which is merely the *magnetic pinion* of Lontin's generators already described on page 98, is composed of an iron cylinder to which are riveted a series of iron plates somewhat resembling the teeth of a pinion, and on these the magnetizing coils A A are wound for tension. In order that the spires of the coils may not shift under the influence of the centrifugal force, and of the elongation caused by the rather large amount of heat developed, the plates of iron forming the cores are thicker at their free extremities than at their points of connection with the iron cylinder, and this greater thickness plays the part of retaining discs for the spires, which are further maintained in their position by abutting against horizontal iron pieces mounted on two bronze wheels. Finally, the coils are so wound that the polarity of the cores are reversed from one plate to the other, so that the motion of the drum brings magnets of alternately opposite poles before the iron cores of the induced system, which thus receive alternately reversed polarizations.

This inducing system is of course magnetized continuously by the dynamo-electric generator, which we have already described, and which may be mounted on the same axle. Another machine may, however, be substituted for this generator; or even a voltaic battery may be used, but in that case the conditions will be very disadvantageous as regards economy.

The induced system is composed, as we have seen, of a large stationary iron ring, fitted inside with a series of iron plates fixed transversely, like the teeth of a wheel projecting internally, and surrounded with magnetizing coils, B B B. These coils are connected to each other in couples, so as to form a complete electro-magnetic system, and their free ex-

termities end severally in the commutator *M*, which enables all the currents they supply to be drawn off separately or collectively by means of the rubbers *a s*. Inside of this ring revolves the inducer, which is so arranged that the magnetic cores of the two systems pass each other without touching. Thus each of the induced systems is magnetized in opposite directions alternately; for if one of the cores of the inducing system, acting on one of the cores of the induced system, is polarized north, the adjoining core of the induced system will be subjected to the action of a south polarity, and a current will always be produced in the induced system connected with the commutator. When the inducer has advanced, the polarities will have different signs, and a current in the reverse direction will be obtained.

As the action we have examined will be simultaneously repeated in all the electro-magnetic systems of the induced bobbins, each of these is able to supply its own action and is independent of the rest, an arrangement which allows of the division of the electric effect. Supposing that each of the induced magnetic systems formed of two bobbins is capable of supplying a current powerful enough to maintain an electric light, the machine represented in Fig. 33 would give 12 lights, and if these were desired of different intensities, it would be necessary merely to take away currents from some of the lights and put them in communication with those lamps that are to be brightest. As the induced system is fixed, nothing is easier than to combine the lights in any required manner, and as there are neither rubbers nor revolving contacts no loss of electricity can occur.

The commutator *M* is so arranged as to act on as many contact plates as the machine supplies currents available for the production of light. The number of these currents depends on the construction of the machine, and we have seen that the one represented in Fig. 33 furnishes twelve currents. There are therefore twelve contact plates, and to each of these correspond two binding screws, one of which

is connected with the contact itself, while the other communicates with a hand circuit-breaker, 1. The former receives the wire of the corresponding magnetic system, the latter the wire which leads to the electric lamp. Moreover, the various contacts are themselves provided with handles, which connect them two by two and enable an instantaneous union or separation of the partial currents to be made.

This machine has for some time been applied to the lighting of the terminus of the Lyons railways, where it supplies 31 electric lights. These lights are produced by a single electric generator and from two induced systems of 25 coils each. By joining these coils together, and interposing in each of their circuits several electric light regulators on the Lontin system, it has been found possible, by a combination of the coils suitable to the length of the circuit, to carry to 31, as I have said, the number of illuminated points, each equal to nearly 40 Carcel lamps.

For six months these machines have been established at the terminus of the *Chemins de Fer de l'Ouest* (*Saint-Lazare* station), where they supply 12 lights, two of which, placed at the entrance to the station, are 700 metres from the machine, a fact that triumphantly replies to the objection made by some persons to the use of alternately reversed currents, which, according to them, would be incapable of producing light at a greater distance than 200 metres.

Gramme's System.—This system is merely a modification of the foregoing, only the induced apparatus is formed of a rather long iron cylinder fixed horizontally, as shown in Fig. 34, and otherwise arranged like the ring in the same inventor's machines. All the small coils, however, A A, which surround this cylinder, instead of being attached to a collector, are distributed in four separate series, each connected with a particular circuit, so that they successively supply the current to four different circuits. The inducing system is a kind of magnetic pinion formed of eight straight electro-

magnets, B B, which move inside of the cylinder, as in the foregoing apparatus, and which, being of contrary polarities, successively supply in each section of the induced coil currents alternately reversed. This inducing system is excited by a Gramme generator like that described on page 74.

It is this system of machines which supplies the currents

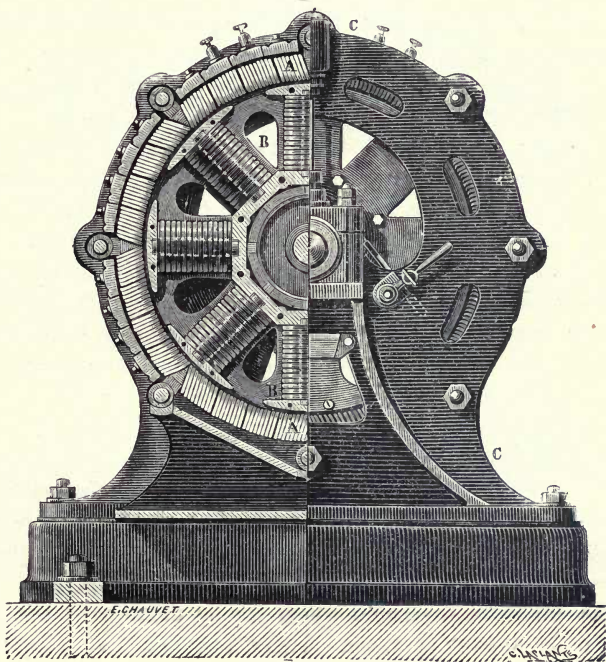


FIG. 34.

required for the lighting of the *Place de l'Opéra*, the *Avenue de l'Opéra*, and the *Place du Théâtre-Français*. Four machines are employed for this purpose; one is placed in the cellars of the opera-house, two others in cellars near the middle of the *Avenue de l'Opéra*, and the fourth is set up in one of the houses adjoining the *Place du Théâtre-Français*.

Each of the currents produced by this kind of machine is able to light four Jablochkoff candles, and consequently each system of machines maintains 16 electric candles. There are, it is true, two candles lighted at once in each lamp in the *Place de l'Opéra*, but there is only one in the lamps of the *Avenue de l'Opéra* and in those of the *Place du Théâtre-Français*.

Experiment has shown that about 1 horse-power of motive force must be reckoned for the maintenance of each of these candles, which, however, last little more than one hour and a half. But to this subject we shall presently return.

In Fig. 34 the machine is shown with one half in section, the other half in elevation. It will be seen that the electromagnetic system is covered up by a cast-iron frame at the two ends, and by a casing of wood on the curved part.

Gramme has recently constructed a new form of these machines, in which the thickness of the wire in the induced coils, their grouping, and their connection with each other, have been so adjusted as to supply the maximum effect with the Jablochkoff candles, while using the least possible motive force. With a horse-power of 4 a machine of small size was capable of lighting eight candles.

This machine is moreover able to supply at pleasure 8, 6, or 4 lights. In the former case it absorbs a horse-power of $4\frac{1}{2}$; in the second, 2.8 horse-power; in the third, 2.1 horse-power. These lights are equal to 25 gas-jets, and the Jablochkoff candles which supply them have carbons 3 millimetres in diameter. Rapiéff's machine, mentioned on page 81, is a machine of this kind.

At the establishment of the *Société général d'électricité* there is also a form of Gramme machine, giving lights equal to from 70 to 84 gas-jets, with carbons 6 to 8 millimetres in diameter. Thanks to these different forms of the machine, lights may now be obtained giving illuminations equal, according to the requirements, to 25, 52, 70, and 84 unshaded gas-jets, and these illuminations are diminished by only

10 per cent. when, instead of enamelled globes, globes of wickered or waved glass are used.

Siemens' System.—Siemens' machines for dividing the light with reversions of currents, which are represented in

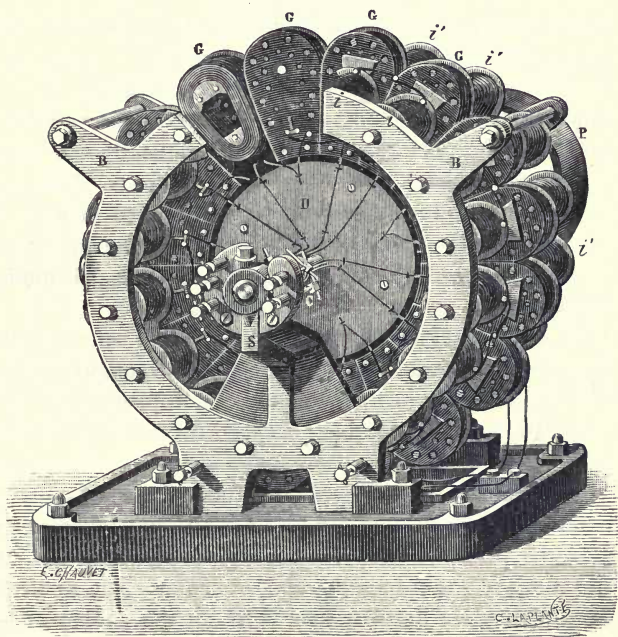


FIG. 35.

Fig. 35, have been constructed for 4, for 8, and for 16 lights. They are, however, also based on the principle of Lontin's system, but under different conditions, and taking advantage of the dynamo-electric effects of the same maker. They require, it is said, a motive force not exceeding 13 horse-power. If we take, for instance, the form of the machine adapted for 16 candles, we observe that the inducing system, instead of being mobile, as in the systems of Lontin and in

Gramme, is formed of the two vertical crowns of electro-magnets, $i\ i$, $v\ v$, fixed parallel to and in front of each other, and turning between them is the induced system constructed of as many galvanometric frames, G G, as there are electro-magnets in each of the two crowns. They are, of course, insulated from the cast-iron frame B B, on which they are mounted by means of ebonite plates, and they are so wound that a north pole is always between two south poles, and *vice versâ*. It will readily be understood that the electro-magnets placed opposite to each other on the two supports are of opposite polarities, and that consequently a galvanometric frame, when it comes between two consecutive cores of this double inducing system, will be affected in four different directions—first on the two faces of the multiplier, and secondly on the two parts opposite to the galvanometric frame.

The induced system is formed of a bronze wheel, on the circumference of which are fixed the 16 galvanometric multipliers, G G, already mentioned; these multipliers are wound on two wooden supports fixed between two plates of copper pierced with holes and having the shape of elongated sectors. Each multiplier is composed of 23 rows of spires, to the number of 17 in each row, and the wire has a diameter of 18 tenths of a millimetre. They have, however, no iron cores, and present exactly the appearance of a galvanometric frame. They are fixed by their sides on the copper wheel, and are fitted with such exactness that one would suppose that the wheel was provided with two large metallic circumferences externally presenting circular notches corresponding with each multiplier. The holes in the metallic sides are for the purpose of admitting air to cool the enclosed multipliers, a precaution neglected in France, but always taken in the machines constructed abroad.

The central part of the wheel of the induced system is occupied by a thick circular plate D, whereon are fixed the wires by which the coils are connected with the collector C

and with each other. The combination of these wires, however, is very simple; the multipliers are divided, as in the Gramme machine, into four series, and those of each series are joined together for tension. One of the similar ends of each series leads to a metallic ring fixed on the axle of rotation of the wheel, and the other ends lead to four other rings insulated from each other, and pressed by the rubbers *c* in communication with the terminal binding screws of the four circuits corresponding with the electric lamps. These circuits are completed by a connection with a rubber which presses on the ring, and is common to all the multipliers. The current of the exciting machine, which is placed beside the other, corresponds, however, with 32 electro-magnets of the two crowns of the inducing system, which electro-magnets are joined for tension, each being composed of five layers of 32 spires, in wire of 2 millimetres diameter. *p* is the pulley for the prime mover.

A remarkable feature of this machine is the small amount of heating it develops. The inducing electro-magnets are seldom higher than 30° C; the multipliers are indeed a little more heated, but I am unable to state their temperature.

According to Boistel, the motive power required to drive this machine for 16 lights will be 13 horse-power (German standard).^{*} The velocity of rotation of the division machine will be 500 turns per minute, and that of the exciting machine 1,375 turns. In the form of the machine intended for 8 lights, the force employed is 7 horse-power, and the speed of the division machine 550 turns; that of the exciting machine 1,375 turns. In the form for 4 lights, the force used is 4 horse-power, the division machine making 600 and the exciting machine 1,100 turns per minute.

Boistel thinks that, by some slight modification, the 4-light machine might be arranged for 6 and the 8-light machine for 12 lights.

^{*} It seems that the "horse-power" used as the unit in Germany is of 80 Liogrammetres instead of 75, which represents that used in France.

The principle of Siemens' machines is based only on the inductive reactions produced by the passage of the spires of the multipliers before an electro-magnetic inducer, and under the influence of a tangential motion. This is not precisely the effect produced in Faraday's classic experiment, and the direction of the currents produced is even different from what it should be, according to the generally received notions of induction. I have studied in detail these different kinds of inductions in a paper presented to the *Académie* on the 24th February, and the substance of this paper will be found in Note A at the end of this volume.

We have lately visited with much interest a large establishment which Siemens Brothers have organized in Paris, at No. 8 *Rue Picot*, for the construction of those machines under the management of Boistel.

Jablochkoff's System. — Jablochkoff has also constructed an induction machine with reversed currents, and

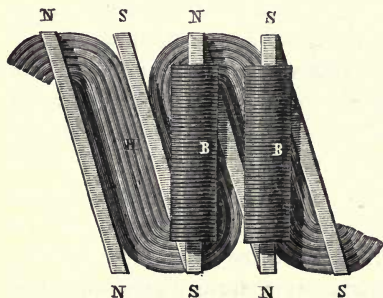


FIG. 36.

with means for dividing the light, which is intended to admit of being more easily cleaned than the Gramme machine, and to work with less motive power without becoming heated. For this purpose Jablochkoff uses for inducers a cast-iron toothed wheel, hav-

ing the teeth slightly inclined to the direction of the axis, and separated from each by a rather wide space. A coil of wire winds between these teeth in the manner shown in Fig. 36, and when this is traversed by a current the teeth assume alternately opposite polarities, which convert

the system into a kind of electro-magnet with numerous poles, acting like Lontin's magnetic pinion. The induced system is formed of a series of straight electro-magnets B B, with expanded poles, and placed parallel to the axis of the wheel crossing its teeth S S, N N, S S, so that when at one end they are in contact with one tooth, at the other end they touch the next tooth. As these teeth are polarized alternately in opposite ways, it follows that for a certain position of the wheel the electro-magnets will be polarized north-south, and this will give rise to magneto-electric currents in the coils which surround them; but when after leaving this position the different parts of the polarized teeth are brought before the different parts of the induced coils, there will be produced these reversed polar currents and dynamic currents which will carry on the magneto-electric action and augment it, as in the machines of De Méritens. Thus, by very simple constructive arrangements, a relatively powerful induction machine is obtained. In the form of the machine working in Jablochkoff's establishment, there are 36 induction coils, and these are so joined as to give three series for tension, each formed of 12 coils joined for quantity. There are, of course, 36 teeth to the wheel, and under these conditions two Jablochkoff candles are kept lighted, with a motive power equivalent to that of two men, but under the influence of an induction current coming from a small Gramme machine. In this way the current from the Gramme machine is transformed under favourable conditions into alternately reversed currents.

COMPARATIVE EXPERIMENTS ON THE EFFECTS PRODUCED
BY THE DIFFERENT ELECTRO-MAGNETIC MACHINES.

The study of the comparative effects produced by the different machines suitable for the electric light is a matter

of great importance, and this has been so well understood that at various times there have been instituted experiments upon it more or less conclusive. As early as 1855 Ed. Becquerel had made an important investigation on batteries as regards this point, and the work was continued by Tresca at the *Conservatoire des Arts et Métiers* with the magneto-electric machines of the *Alliance Company*. At a later period these machines were the subject of laborious investigations, conducted by Reynaud and Degrand at the Directory of Lighthouses. A more profound study of the question was undertaken by Le Roux in 1865, and this was the subject of a very interesting communication printed in the *Bulletin de la Société d'Encouragement* (tome XIV., page 699). Jamin, in conjunction with Rogers, examined from a scientific point of view the work produced by the same machines, and in 1877 Tresca, in a paper read before the *Académie des Sciences*, gave a complete investigation of the effects produced by the Gramme machine. At length the success of these machines, and of their application to lighthouses, so much attracted the attention of the English that in 1877 they considered it necessary to appoint a Commission of Inquiry to examine this question. This Commission was composed of Tyndall, Douglass, Sabine, Edwards, Drew-Atkings, and Minster, with Douglass as reporter; and it shortly afterwards published a Report, known as *The Report of the Trinity House on the South Foreland Lighthouse*, and this was for some time regarded as the best authority on the subject. The Americans, however, were also desirous of examining the question, and the Franklin Institute, after an invitation to the makers of machines to compete, which was responded to by only three, appointed a Commission composed of Briggs, Rogers, Chase, Houston, Thomson, Rand, Jones, Sartain, and Knight, and this Commission, subdivided into three committees, presented a double report, which was published in the Bulletin of the Franklin Institute. We shall give the numerical results from this report after those of the English Commission

Notwithstanding the importance of these documents, we believe the question is far from having been settled, for we find that in them the spirit of nationality has played so large a part that they cannot be implicitly trusted. Nor can we rely on the figures given by the several makers and inventors of the machines. Not only are the majority of these individuals without the scientific acquirements necessary for exact results, but there are personal interests the influence of which it is impossible to eliminate from the statements put forth, and for my part I believe that we must deduct a great deal from the results which have been announced. Amidst this confusion it is difficult to see where we are, and it is much to be desired that an international commission should undertake to completely clear up the question. In the meanwhile we give the results obtained by the English and American Commissions in the two tables on pages 123, 124, and 125, and to these we shall add a third table, drawn up by Shoolbred, from the most recent experiments.

In order to define the values of the figures in these tables, we must mention that the standard for light adopted in them, and denominated a *candle*, represents the light of a spermaceti candle, having an intensity equal to eight-tenths of the light of a *bougie de l'Étoile*. A Carcel lamp represents about $9\frac{1}{2}$ candles (9.6).

In the table of English measurements mention is made of the *condensed radiating power* and of the *diffused radiating power*. It is important that these expressions should be understood. The condensed radiating power, as we have already indicated on p. 21, is applied to the light given off by a continuous current between two carbons, one of which is hollowed out in a cup shape and so turned as to act as a reflector, and to emit the light externally with increase of the illuminating power. The diffused radiating power is that which is produced by a light between two carbons without a cup-shaped hollow.

In the American table mention is made of *foot-pounds*:

this is the unit of moving force which corresponds with our kilogrammetre; it is equal to a kilogrammetre divided by 7.233.

The Report of the English Commission assigned the superiority to Siemens' machine (small form). According to Tyndall this form is best adapted for connecting with machines, and in proportion to its small size its effects are enormous. We must remark, however, that the figures given in the table on pages 125 and 126 for the Gramme machine, relate to machines of the pattern of 1875. Now, the new patterns of 1876 have given results infinitely superior, not only with regard to the yield of the Gramme machines tried in England, but also with regard to the Siemens machines extolled by the English Commission. According to the experiments made in France the values relating to the Gramme machine should be rectified as follows:—

With a machine weighing 175 kilogrammes, making 850 revolutions per minute under a motive power of $2\frac{1}{2}$ horse-power, the condensed radiating power would be 4,297 candles, and diffused radiating power 2,590, which would give for each horse-power 1,719 for the condensed and 1,036 for the diffused radiating power; the Gramme machine would then take the first place in order of merit.

The following are the conclusions of the American Commission:—

After having carefully considered all the facts noted in the reports which have been submitted to it, the Commission has unanimously come to the conclusion that the small form of Brush machine, although in some respects less economical than the Gramme machine or the large Brush machine, for the general production of light and of electric currents, is, of all the machines experimented with, the best adapted to the wants of the Institute, chiefly for the following reasons:—

1°. It is admirably arranged for the production of currents of very different intensities, and it produces a good light.

It is remarkable for the way in which the various mechanical

parts of the machine is arranged, and especially its commutators ; and, moreover, it admits of being easily repaired.

To us it appears extraordinary that a machine with commutators can realize the advantages referred to in this Report ; and we believe that if this machine had been removed from the realm of scientific experiment and placed in that of practical use, the conclusions would have been very different. We think, too, that the question is far less understood in America than in Europe ; and this is also the opinion of several American men of science.*

* John Trowbridge, in the *Scientific American* of the 11th January, 1879, thus expresses himself on this subject :—

With regard to the electric light America is far behind Europe as regards the progress recently made, and unless some great invention is suddenly made in this country and sanctioned by the Patent Office, we must not look for novelties here.

This inferiority exists not only in the number and variety of the lamps which have been brought before the public, but also in the arrangement of the dynamo-electric machines. We see in Europe, side by side with various forms of Siemens' machines, those of Gramme, of which Schuckert's machine is merely an interesting form, and which have been so arranged as to supply alternately reversed currents, a condition necessary for the regular consumption of the carbons used in the electric lamps. We see also the Lontin machines, which give the same results. It seems that to obtain the same quantity of light less motive force is required with the foreign than with the American machines, and a lower velocity is required for working them, which is a great advantage.

America has not yet been able to produce an electric regulator working as well as that of Serrin, and the foreign carbons are superior to those met with here. We have not yet seen the carbons metallized by electrotyping processes, which prevent their heating beyond the point of combustion, and which have long been known in France. The Brush lamp and the Wallace lamp, the best known in America, answer well for the purposes of general illumination ; and in this country there are not more than a dozen establishments lighted by the electric light, while on the old continent they are reckoned by hundreds. Nor has illumination by incandescence succeeded in America, whether the carbons have been placed in a vacuum or in nitrogen, whether wires of platinum and iridium or filaments of platinized asbestos have been used. The carbons fall to pieces or crack after a certain time, or perhaps the metal fuses. However, the two plans we have just mentioned, carbons and incandescent wires, have been tried in Europe, and have been found more costly than the system of lighting by gas.

The conclusions of Elihu Thompson and J. Hudson are however, somewhat different, and in our opinion more correct. They are separately stated in this way :—

1°. The Gramme machine is the most economical as a means of converting motive force into electric currents ; it utilizes in the arc from 38 to 41 per cent. of the motive work produced, after deduction is made for friction and the resistance of the air. In this machine the loss of power due to friction and to local actions is smallest, doubtless on account of its smaller speed. If the arc is maintained in its normal condition scarcely any heating is produced in the machine, and the presence of sparks at the commutator can hardly be perceived.

2°. The large Brush machine comes second in the order of efficiency. It produces in the luminous arc useful work equivalent to 31 per cent. of the motive power employed, or to $37\frac{1}{2}$ per cent. after the friction has been deducted. It is, in fact, but little inferior to the Gramme machine, but it has the disadvantage of requiring a very high speed, and consequently there occurs a greater loss on account of friction. This disadvantage is, it is true, compensated by its power of working with a greater external resistance compared with the internal resistance of the generator, and this, in a manner, does away with the heating of the machine. It is this machine, moreover, which has given the most powerful light and the most intense currents.

3°. The small Brush machine ranks third, with a useful work in the arc estimated at 27 per cent. of the motive power employed, or 31 per cent. with deduction for friction. Although this machine is in some respects inferior to the Gramme machine, it is nevertheless admirably contrived for the production of currents of intensity, and it can be made to produce currents of very different electro-motive force. By suitably arranging this machine, the electro-motive force may be increased from 55 to 120 volts, and the currents it produces may be divided between two circuits, an advantage, however, which is possessed by other machines. The simplicity of the commutator and the facilities for repairs which the arrangement allows, are also advantages to be taken into consideration. This machine, moreover, does not produce much heating.

4°. Wallace Farmer's does not yield in the working circuit

so large a proportion of the motive power as do the other machines, because it uses up a large part of its power in electrical work and in a small space, in consequence of too much having been sacrificed in the production of local actions. By remedying this defect a very good machine might be made of it.

We regret that a machine of the Siemens type has not been placed at our disposal. Whatever may be its value, our determinations would have been of importance as supplying data for a machine so well known and in which the induced armature is so different as regards its principles from those of the other machines, and which, by the manner the wire is wound, theoretically favours the work.

Thomson and Houston point out that if it is desired to compare the results obtained by them with those of the English Commission it is necessary, on account of the different arrangements of the carbons of the regulator adopted in the English experiments, to divide by 2.87 the numbers representing the condensed radiating power. Still the number obtained to represent the luminous power of the Gramme machine would be too great, being 438 candles, whereas they found it to be only 383 candles. This circumstance indicates that we cannot trust entirely to all these figures, for this very number these gentlemen have found to be too high seems to us in France to be much too low. In all these photometric measures there is evidently a sad want of agreement, which shows that all the experiments must be repeated.

In the meantime we think that we ought to record here the results of experiments made with the Gramme machine by several French engineers and men of science whose names are a sure guarantee for their accuracy.

We shall begin with Tresca's experiments, carried out at Sautter & Lemonnier's, with two Gramme machines, the large and the small form, which, driven with a velocity of 1,274 turns per minute for the large form and 872 turns for the small form, yielded respectively light equal to 1,850 and 300 Carcel lamps. I have given in my *Exposé des applications*

d'électricité, tome V., p. 542, the details of these experiments, and I shall here content myself with indicating the results.

According to these experiments it would follow that the mean work in kilogrammetres per second of the large machine is 576·12, or 7·68 candles, which gives for a light of 100 Carcel lamps 0·415 horse-power; for each light per second 0·51 kilogrammetres. For the small machine this work is 210·65 kilogrammetres, or 2·81 horse-power, which gives for a light of 100 lamps 0·92 horse-power, and for one lamp per second 0·69 kilogrammetres.

“The machines,” says Tresca, “worked with regularity for a time sufficiently long to show that there was an absence of all sensible heating. The work expended varied very little during the course of the different series of experiments, although one of the determinations had been made after the machine had been driven for a long time.

According to the experiments made at Mulhouse by Heilmann, Ducommun, and Steinlen, who now use this method of lighting, each of their lamps, which supplied a light of 100 lamps, required only 1·65 horse-power of mechanical force to be expended.

Experiments made by Schneider and Heilmann with several machines gave the following results:—

Description of Machine.	Number of turns per Minute.	Work expended in Horse-power.	Luminous intensity measured by Bunsen's Photometer.	Remarks on the Regulators.
Machine B ...	816	1·921	95·6	{ with ground glass globe.
Machine B ...	816	1·921	122·2	without globe.
Machine B ...	804	1·980	86·8	—
Machine A ...	810	1·849	85·3	—
Machine C ..	763	1·833	103·2	—
Machine D ...	883	1·360	68·7	—

These last results are less favourable than those obtained by Tresca; but we must not lose sight of the fact that he was operating under exceptional conditions, and had perhaps not taken into account the condensed luminous power. From all these experiments, however, the motive power required

for a light of 100 Carcel lamps may be taken as between 0.92 and 1.80 horse-power, and reckoning from the mean of these, 1.47—a number very near that found by Heilmann and Ducommun—we have 70 Carcel lamps for each horse-power, with a speed of 850 rotations per minute. According to Tresca's figures this would be 103 lamps, or 1,036 candles.

According to experiments made with the Jablochkoff candle in Jablochkoff's workshops, the quantity of light per horse-power would be represented by 23 gas-lights for the machines of De Méritens, by 28 or 30 lights for the Gramme machines, and by 30 or 32 lights for the Siemens machines.

It will be perceived that the real value of these results is by no means agreed upon; but it must also be admitted that the experiments are very difficult to make on account of the luminous effects, which exhibit considerable differences from one moment to another.

We must call the reader's attention to one important remark that has been made on the results yielded by the machines according as the light is concentrated or divided.

According to the comparative experiments that have been made, it would appear that a much greater motive power is required to obtain the same light when it is divided among several lamps than when it is concentrated at one point. In the *Courrier des États Unis* of the 28th January, 1879, we read thus:—

Given a light of one lamp equivalent to 15,000 candles, the same quantity of light divided between five lamps inserted in the same circuit will be reduced to 2,000 or 3,000 candles for the same motive power; in other words, it would be necessary to use five or six times as much power to produce a divided light as to produce a single light, and this proportion will increase with the number of divisions. If, however, this principle is correct, it will have its counterpart and corrective in that other principle, which also rests on a progressive scale: namely, that by increasing the power generating the electricity beyond what is necessary to produce a certain quantity of light, say 15,000 units for a single lamp, the loss by the division of the current

will diminish, not in direct proportion, but in progressive proportion to the excess of power employed. Thus, if 80 horse-power are required to produce 15,000 units of light at one lamp, and if the light is, by division, reduced to 200 units, 160 horse-power will produce not simply 400 units, but a much larger proportion, which will increase, not by addition but by multiplication, in proportion to the excess of power employed. It is, therefore, not impossible to obtain a divided light with a certain intensity, but on condition that the quantity of electricity produced shall be raised to a power much greater than that which will give a single light representing the same number of candles.

The question is to ascertain the proportion between the two terms, that is to say, whether the amount of power required for useful division be not out of proportion with the result obtained, or in other words, if enormous apparatus would not be required for an inconsiderable effect. This reduces the problem to the total cost of erection and maintenance. The question may be thus stated: If 80 horse-power produces a light of 15,000 candles in a single lamp, how many horse-power would be required to bring up the light to the same value of 15,000 candles when divided among several lamps?

Edison is seeking for the solution of this problem, which it would seem he has not yet found. This is the one important question. Edison has also to invent a generator of unheard-of power, and in this he says he is sure of succeeding. But in the meantime he has to try those which are at present in use, in order, no doubt, to find which comes nearest to his ideal, that it may supply the most advantageous data for constructing his own.

EFFECTS OF THE RESISTANCE OF EXTERNAL CIRCUITS.

If we were to take into consideration only the proper resistance of the conductors composing an external circuit, it is evident that the maximum of electric intensity, yielded by the generator, would be obtained when the external circuit

had the minimum resistance. But as, in order to produce the electric light, a part of this external circuit must have a certain resistance, this resistance becomes useful; and we have seen that, according to Joule's law and also according to the experiments of Jamin and Becquerel, the maximum effect is obtained when this useful resistance is equal to the useless resistance, plus that of the generator. It is, therefore, the resistance of the arc which has to be especially considered from this point of view; and it will always be advantageous to diminish as much as possible the resistance of the conductors used for simply conveying the electricity. Under these conditions the loss to which the light is liable may take place in greater or less proportion, according to the resistance of the generator. This is to a certain extent explained by the circumstance that, the resistance of the conductors being added to that of the generator, the former tells more in the final result in proportion as the latter is smaller. It must, besides, be remembered that the increase of the unutilized resistance of the circuit, by diminishing the intensity of the electric current, diminishes the energy of the mechanical resistance opposed to the motor, and by allowing it to acquire greater speed renders the loss of electric intensity less marked. The reverse will, of course, occur when the resistance of the circuit diminishes instead of increasing.

The following results of some experiments made at the South Foreland will illustrate these remarks. Between the lighthouse and the building containing the machines, a distance of 694 feet, there were carried for the electric light three cables, two of which were each formed of seven copper wires No. 14 (Birmingham Wire Gauge), and were joined to constitute the circuit, thus giving a total length of 1,286 feet, with a resistance of 0.32 of Siemens' unit, or about that of 33 metres of telegraph wire.

With Holmes' machine, which had the greatest resistance, the loss of luminous intensity was estimated at 16.1 per cent.; with the Gramme machine, of much less resistance, it was

estimated at 31·3 per cent. ; and with Siemens' machine, having the least resistance of all, it reached 43·4 per cent. By using a cable of less resistance, this loss was reduced to 23 per cent. with the Siemens machine, but it became 35 per cent. when, by coupling two Siemens machines for quantity, their total resistance was reduced by one-half. The employment of this cable of small resistance with one of the Alliance machines caused a loss of 69·1 per cent. of the total light, and with Holmes' machine the loss became 66·1 per cent. With two Holmes machines coupled the loss rose to 76·5 per cent. These experiments show, therefore, that in order to realize the conditions necessary for the maximum of light, the resistance of the conducting wires must have a certain relation to that of the machine. (*See Note B*).

RESULTS PRODUCED BY COUPLING TWO MACHINES.

According to the experiments made at the South Foreland with coupled magneto-electric machines, it has been found that the light produced by two coupled machines was more intense than the sum of the lights produced by each acting separately. Thus two Siemens machines having separately given lights, the intensities of which were represented by 4,446 and 6,563 candles, supplied when joined for quantity a light equal to 13,179 candles, or 19·7 per cent. more than the sum of the lights produced separately. This result is not peculiar to the Siemens machines, for the same occurs with the Gramme machines ; but with the former it is much more marked. These results are shown in the table on pages 124 and 125. They prove that, as we have already stated in page 119, as regards the luminous intensity, there is a greater advantage in concentrating the electric action at a single lamp than in dividing it among several.

TABLE OF THE AMERICAN EXPERIMENTS.

NAMES OF THE MACHINES.	Weight in Pounds.	COPPER WIRES.				Revolutions of the Armature in one Minute.	Foot-Pounds of Power expended for each Candle of Light.	Horse-Power.	Light in Candles.		Foot-Pounds of Power expended for each Candle of Light.	Sizes of Carbons.	Length of Carbon consumed per Hour.	
		Of the Armature.		Of the Magnetic System.					Total.	Per Horse-Power.			+	—
		Size.	Weight	Size.	Weight									
Large Brush ...	475	in. ·81	lbs. 32	in. 134	lbs. 100	1,340	107'606	3'26	1,230	377	87'4	in. $\frac{3}{8} \times \frac{3}{8}$	in. 1'78	in. 0'34
Small Brush ...	390	·63	24	96	80	1,400	124'248	3'76	900	239	137	$\frac{5}{8} \times \frac{5}{8}$	1'91	0'58
Large Wallace.	600	·42	50	114	125	800	—	—	823	—	—	—	—	—
Small Wallace.	350	·43	18½	98	41	1,000	128'544	3'89	440	113	292	$\frac{1}{4} \times \frac{1}{4}$	2'45	0'075
Gramme.....	366	·59	9½	108	57½	800	60'992	1'84	705	383	85	$\frac{1}{4} \times \frac{1}{4}$	3'15	0'55

COMPARATIVE TABLE C

KIND OF MACHINE.	Price.	Dimensions.			Weight.	Motive Force absorbed in Horse-power.	Number of Revolutions per Minute.
		Length.	Width.	Height.			
HOLMES	£ 550	feet. 4'92	feet. 4'32	feet. 5'24	lbs. 5,740	3'2	400
ALLIANCE	494	4'32	4'49	4'82	4,075	3'6	400
GRAMME, No. 1 ...	320	2'58	2'58	4'06	2,853	5'3	420
GRAMME, No. 2 ...	320	2'58	2'58	4'06	2,853	5'74	420
SIEMENS, large size ...	265	3'62	2'32	1'17	1,305	9'8	480
SIEMENS, medium } size, No. 58	100	2'16	2'32	0'83	420	3'5	850
SIEMENS, medium } size, No. 68	100	2'16	2'32	0'83	420	3'3	850
2 HOLMES, coupled	1,100	9'84	4'32	5'24	11,480	6'5	400
2 GRAMMES, coupled	640	5'16	2'58	4'06	5,706	10'5	420
2 SIEMENS, medium } size, Nos. 58 & 68 } coupled	200	4'32	2'32	0'83	840	6'6	850

THE ENGLISH EXPERIMENTS.

Total Luminous Intensities.				Luminous Intensities for each Horse-power of Force absorbed.				Classification of the Machines in order of Merit.
Condensed Light.		Diffused Light.		Condensed Light.		Diffused Light.		
Cand-les.	Carcel Lamps.	Cand-les.	Carcel Lamps.	Cand-les.	Carcel Lamps.	Cand-les.	Carcel Lamps.	
1,523	217'57	1,523	217'57	476	68'00	476	68'00	6
1,953	279'00	1,953	279'00	543	77'57	543	77'57	5
6,663	951'86	4,016	573'71	1,257	179'57	758	108'29	4
6,663	915'86	4,016	573'71	1,257	179'57	758	108'29	4
4,818	2116'86	8,932	1276'00	1,512	216'00	911	130'14	3
5,539	791'29	3,339	477'00	1,582	226'00	954	136'29	2
6,864	980'57	4,138	591'14	2,080	297'14	1,254	179'14	1
2,811	401'57	2,811	401'57	432	61'71	433	61'71	—
1,396	1628'00	6,869	981'29	1,085	155'00	654	93'29	—
4,134	2019'14	8,520	1217'14	2,141	305'86	1,291	184'43	—

TABLE OF NEW EXPERIMENTS

	Number of Candles for each Light measured horizontally.		Revolutions per Minute.	Lamps used.	Nature of the Motor.	Engines.		
	Total.	Per Horse-power absorbed.				Revolutions per Minute.	Diameter in Inches.	Strokes in
Holmes.....	1,523	476	400	Holmes	Steam	—	13	1
Alliance.....	1,953	543	400	"	"	—	—	—
"	3,000	667	400	Serrin	"	—	—	—
Méritens, large	8,600	1,228	650	Holmes	Gas...	156	9	1
" small	1,860	1,240	880	Duboscq	"	156	9	1
Siemens, medium	4,100	1,254	850	Siemens	Steam	—	13	1
" "	—	—	—	"	Gas...	158	9	1
" small	—	—	—	"	"	155	9	1
Gramme, for a single light, (A) }	960	320	—	Serrin	Steam	115	—	—
" " ...	1,824	730	920	"	"	—	—	—
" " ...	2,850	1,018	892	"	"	—	—	—
" " ...	2,520	740	830	"	Gas...	143	6 $\frac{1}{2}$	1
" " ...	705	383	800	Brush	Steam	—	6	—
Large Brush.....	1,230	377	1,340	"	"	—	6	—
Small "	900	239	1,400	"	"	—	6	—
Large Wallace.....	823	—	800	"	"	—	9	1
Small "	440	113	1,000	"	"	—	6	—
Gramme Division Ma- } chine, 16 lights	250	—	640	Jablochkoff...	"	—	—	—
Gramme Division Ma- } chine, 20 lights	—	—	650	" ...	"	142	10	1
Lontin Division Ma- } chine, 6 lights	570	—	350	Serrin-Lontin	"	110	9 $\frac{1}{2}$	1

Engines.			Remarks.		
Horse-power per Light.					
NOMINAL.	EFFECTIVE.		Localities.	Observers.	Observations.
	Total.	Absorbed.			
10	—	3'2	South Foreland.....	Douglass	} Alternating Magneto- Electric Currents.
10	—	3'6	"	"	
—	—	4'5	Paris	Allard	
8	10'9	7'0	Royal Institution	Douglass	
8	4'2	1'5	"	"	} Dynamo- Electric Machines with Continuous Currents.
0	—	3'3	South Foreland	"	
8	8'9	5'4	{ London Stereo- scopic Co. }	Amos.....	
8	8'2	4'7	"	"	
2	3	2'7	La Chapel'e, Paris ...	{ Chemin de fer du Nord }	
—	—	2'5	Rouen	Powell	
—	—	2'8	Paris	Tresca	
3'5	5'1	3'4	{ Edmundson, West- minster }	Shoolbred.....	
—	—	1'84	Philadelphia	{ Committee of the Franklin Institute }	
—	—	3'26	"	"	
—	—	3'76	"	"	
—	—	—	"	"	
—	—	3'89	"	"	
0	—	1'25	{ Avenue de l'Opéra, Paris }	Allard	} Dynamo- Electric Machines with Alternating Currents.
0	—	—	Thames Embankment	"	
9	—	—	{ St. Lazare Station, Paris }	{ Chemin de fer de l'Ouest }	

APPARATUS FOR EVOLVING THE ELECTRIC LIGHT.

Light produced between carbon electrodes.—We saw at the beginning of this work that the electric light was produced by the passage of an electric discharge or current through a gaseous or solid body having a conductivity sufficiently small to become incandescent from the enormous heat developed by the passage of the electricity. We saw also that in order to obtain this light under the most favourable conditions it is necessary to use electrodes made of substances capable of disintegration, and of ready combustibility, and that of all substances carbon is that which yielded the best results.

It was Davy who first conceived the idea of using carbons as electrodes for producing the voltaic arc, but these carbons were sticks of charcoal quenched in water. These were, however, so quickly consumed that other physicists endeavoured to substitute a more durable form of carbon for the wood charcoal. Foucault was the first to make use of that product of coal which is deposited in the inside of the retorts employed in gas-making. He thus obtained a voltaic arc of much greater durability.

There was, however, much that was objectionable in retort-coke, from its want of uniformity and from its admixture with earthy matters, which caused the light produced to be far from steady. The carbons were destroyed also in consequence of the fusion of the siliceous matter contained in them, and generally emitted vapours which, being better conductors than the arc, carried off a portion of the current as a non-luminous discharge.

It is true that by suitably choosing these carbons, and by cutting them from the uniform portions of the deposits, good ones might be obtained ; but this material for the voltaic arc

has long been objected to, and has often proved an obstacle to the applications of the electric light. Yet even at the present time, and in spite of the progress which has recently been made in the preparation of carbons for the electric light, there are some who prefer the retort-coke.

The above mentioned inconvenience of retort-carbons, as may readily be supposed, soon caused physicists and manufacturers to seek a method of preparing them of a purer chemical composition, and with a more uniform physical constitution. By certain processes of which we shall presently speak, this has gradually been achieved. Into the composition of these artificial carbons certain metallic salts have sometimes been made to enter, in order that, under the threefold influence of the electrolytic, the calorific, and the reducing actions, the metals of the salts might be deposited on the negative pole, where their combustion in the air would increase the light of the arc itself. Carré, Gauduin, and Archèreau have made experiments of this kind, which we shall describe farther on; but the results have not been entirely satisfactory, as the light has generally been rendered flickering and unsteady. The simple carbon has therefore commonly been preferred.

The resistance of the carbons is very variable. When they are of uniform section and quality the resistance is, of course, dependent on their length or thickness. Experiments made at Silvertown by Hospitalier and Robert Gray have shown a resistance of 3.25 ohms per lineal metre for Carré's carbon of 4 millimetres diameter. A copper conductor of the same dimensions would have a resistance of only 0.001315 ohm, and therefore the copper conducts 2,471 times better than the carbon. These figures may occasion surprise, but it should be remembered that they relate to carbons of small diameter, and that, if referred to carbon of 1 centimetre in diameter, the resistance is not more than 0.52 ohm, or about 50 metres of telegraph wire.

As early as the year 1846 Staite and Edwards had patented

electrodes for the electric light, made of a mixture of pounded coke and sugar, which, after having been moulded and powerfully compressed, was baked, then steeped in a concentrated solution of sugar, and heated again to whiteness. Three years afterwards, in 1849, Leonolt patented carbons for the same purpose, made of two parts of retort-coke, two parts of wood charcoal, and one part of liquid tar. These substances were mixed into a paste, then subjected to powerful compression, afterwards covered with a coating of sugar-syrup, and left for 20 to 30 hours at a high temperature. They were afterwards purified by successive immersions in acids. Lacassagne and Thiers conceived the idea of purifying sticks of carbon by steeping them in fused caustic, potash, or soda. The object of this operation was, according to the author, to change the silica contained in the carbon into soluble silicates. They were then steeped a few moments in boiling water, and afterwards exposed to a current of chlorine in a porcelain tube heated to redness, in order to convert the earths left unattacked by the potash or soda into volatile chlorides of silicium, calcium, potassium, iron, &c. A short time after these experiments Curmer proposed to form carbons by the calcination of a mixture of lamp black, benzine, and turpentine, the whole moulded into a cylindrical form. The decomposition of these substances left a porous coke, which was saturated with resin or syrup, and again calcined. These had little density and a low conducting power, but they were very uniform and free from all impurities.

The greatest success was, at the period we are speaking of, obtained by Jacquelain, formerly the chemist of the *École Centrale*. Experiments on the electric light made with his carbons for the French lighthouse authorities were so conclusive that the problem was supposed to be solved. In connection with these experiments I cannot refrain from giving here a letter written to me in 1858 by Berlioz, at that time manager of the *Alliance* Company, a man of intelli-

gence, who was then most enthusiastic as to the results obtained by his machines:—

. . . I ought to have written sooner to tell you about the machine: it works perfectly well and with increasing power, and we have an *admirable light*. I wanted to tell you of this, which I consider of consequence, for, as usual, we have to thank you for this important matter. You induced me to see Jacquelain about his pure carbon coke, and this coke gives a *steady light without flame*, and of remarkable brilliancy. I am sorry you are not here, as you have been kind enough to bestow a fatherly care upon our machine. This evening I am showing the light to my superintending committee. We are able at a distance of 60 metres to read very small writing, and no doubt we could read at nearly a kilometre if space permitted. We have also magnificently illuminated the dome of *Les Invalides*, which is about 300 metres from our apparatus; but I hope we shall soon perform the experiment on the Seine in a steamboat, as you advised.

Thus with our machine taking the place of the voltaic pile, with the Jacquelain carbons, a regulating mechanism suited for alternately contrary currents, and a good reflector, the problem of electric lighting on sea-going ships will be completely solved.

Jacquelain's Method.—To obtain a pure carbon Jacquelain makes use of the carbides of hydrogen, either those obtained in the distillation of coals, shales, turf, &c., or the numerous products formed during the carbonization of these combustibles in close vessels, or those represented by the heavy coal, shale, or turf oils, or by volatilizable organic substance.

“These organic materials,” says Jacquelain, “contained in a cast-iron receptacle, are introduced into a cast-iron boiler on a lower level by a conducting pipe furnished with a cock. The boiler is also provided with a cock for emptying it. The vapours are carried by a cast-iron pipe into a horizontal retort made of refractory earthenware, and fitted with a screen for retarding the passage of the gaseous products. This communicates with two cast-irons receivers, forming an inverted U, where the lamp

black is collected. Any obstruction in the retort is removed by means of a scraper. From the last receiver which forms the second branch of the inverted U, a curved pipe leads the hydrogen gas and the undecomposed volatile products under a grating."

Unfortunately this process was very incomplete, and offered no security for the quality of the products. Along with excellent carbons giving very satisfactory results there were others very bad, and sometimes even worse than those obtained from retort-coke. Therefore Carré determined to study the problem afresh, and he thus speaks of it in the *Comptes rendus de l'Académie des Sciences* of the 19th February, 1877, p. 346 :—

Carré's Method.—"The superiority for various experiments of artificial carbons, and the possibility of purifying by alkalis, acids, aqua-regia, &c., the carbonaceous powders that enter into their composition, then led me to seek for some means of producing them economically. By moistening the powders either with syrups of gum, gelatine, &c., or with fixed oils thickened with resins, I succeeded in forming pastes sufficiently plastic and consistent to be forced into cylindrical rods through a draw-plate placed at the bottom of a powerful compression apparatus under the pressure of about 100 atmospheres. Carbons are now manufactured by this process, and I have at various times presented some of them to the *Académie des Sciences* and to the *Société d'encouragement*.

"These carbons have three or four times the tenacity and are much more rigid than retort-coke carbons, and cylinders of 10 millimetres diameter may be used of a length of 50 centimetres without any danger of their bending or crossing during the breaks of the circuit, which often happens with others. They may be as easily obtained of the slenderest diameters (2 millimetres) as of the largest.

"Their chemical and physical homogeneity gives great steadiness to the luminous arc; their cylindrical form, combined with the regularity of their composition and structure, causes their cones to continue as perfectly shaped as if they had been turned

in a lathe, and therefore there are no occultations of the point of maximum light like those produced by the projecting and comparatively cold corners of the retort-coke carbons. They are not liable to the inconvenience of flying in pieces when first lighted, as the others are, in consequence of the great and sudden expansion of the gas contained in their closed cellular spaces, which are sometimes 1 cubic millimetre in capacity. By giving them one and the same uniform density they are consumed by the same amount for an equal section; they are much better conductors, and, without the addition of any substances other than carbon, they are even more luminous in the proportion of 1.25 to 1."

The preparation preferred by Carré is a mixture of powdered coke, calcined lamp black, and a syrup made of 30 parts of sugar and 12 parts of gum. The following formula is given in his patent of the 15th January, 1876:—

Very pure coke, finely powdered	...	...	15 parts.
Calcined lamp black	...	...	5 "
Syrup of sugar	...	...	7 to 8 "

The whole is well pounded together, and from 1 to 3 parts of water are added to make up for the loss by evaporation, and to give the required degree of consistence to the paste. The coke is to be made with the best samples ground and purified by washing. The paste is then compressed and passed through a draw-hole, and the carbons are afterwards piled in crucibles and exposed for a certain length of time to a high temperature. Details of the operations for preparing these carbons will be found at page 54 of H. Fontaine's work.

We may add that Carré, being desirous of imparting to the electrical light the hues most suitable for theatrical purposes, has succeeded in so treating his carbons that they impart to the light a tint which, instead of being bluish-white, has a rosy-yellow hue, that is very advantageous for bringing out the complexions of the actresses.

Carré's manufacture has, since the great experiments made

by the Jablochkoff Company, been much extended, and, thanks to the large scale on which his process is being carried out, he can now send out carbons 50 per cent. better than at first. These carbons are now at a price which allows of their practical use, and this circumstance greatly conduces to the development of the applications of the electric light.

Gauduin's System.—The carbons manufactured by Gauduin are of pure carbon, their base being lamp black; but as the price of this substance is comparatively high, and its management is difficult, Gauduin was obliged to seek for a better source of carbon, and he obtained it by heating in a closed vessel common rosin, pitch, tars, resins, bitumens, natural and artificial oils, essences, or organic matters, which, after decomposition by heat, leave sufficiently pure carbon.

These products are put into crucibles and heated to bright redness, the volatile matters being conducted into a condensing chamber, whence they are carried by a copper worm-tube with the condensed liquids, such as tars, oils, spirits, and carbides of hydrogen, into another worm-tube, where they are collected for use in the manufacture of the carbons. There remains in the retort some more or less compact carbon, which is pulverized as finely as possible, and collected either alone or mixed with a certain quantity of lamp black by means of the carbides of hydrogen obtained as secondary products.

Thus prepared, these carbons are completely free from iron, and are superior to those met with in commerce. For moulding his carbons the inventor uses steel moulds capable of withstanding the highest pressure of a powerful hydraulic press. The moulds are arranged like draw-plates, and their arrangement has been much improved by Gauduin, for in his process the sticks are supported throughout their whole length, so that they do not break by their own weight, as often happens with ordinary draw-plates.

Quite recently Gauduin has further improved his process.

Instead of carbonizing wood and reducing the charcoal to powder, he selects a suitable piece of wood, which he cuts to the shape required in the carbon; then he converts it into hard charcoal, and finally soaks it, as in the manufacture we have described. The heating of the wood is conducted slowly so as to drive off the volatile matters, and the final heating takes place in a reducing atmosphere at a very high temperature. All impurities are removed from the wood by a preliminary washing in acids and in alkalis.

Gauduin also points out a method of stopping the pores of the wood by heating it to redness and exposing it to the action of chloride of carbon and various carbides of hydrogen. He expects thus to produce electric carbons which will be very slowly consumed and will give a light absolutely steady.

These carbons have not, however, done what was expected of them, therefore they have not become general, and are little used except by the firm of Sautter and Lemonnier. At the present time it is difficult to obtain them, and it is doubtful if they can compete with those of Carré, who employs as his raw material a very cheap substance, namely coke.

Effects produced by the addition of Metallic Salts to the Carbons prepared for the Electric Light.

—As we have already seen, page 129, attempts have been made to obtain some advantage by associating the carbons with metallic salts, which might supply, independently of the voltaic arc, a light due to the combustion of the metal carried to the negative electrode. The following experiments have been undertaken by Gauduin, Carré, and Archereau:—

Gauduin mixed the following substances with the pure carbon:—phosphate of lime from bones, chloride of calcium, borate of lime, silicate of lime, pure precipitated silica, magnesia, borate of magnesia, alumina, silicate of alumina. The proportions were so calculated as to leave 5 per cent. of oxide after the carbons were dried. They were submitted to the action of an electric current always in the same direction, supplied by a Gramme machine sufficiently powerful to main-

tain an arc of 10 to 15 millimetres long. The following results were obtained :—

1°. The phosphate of lime was decomposed, and the reduced calcium burnt in the air with a reddish flame; the light measured by the photometer was double that given by retort-coke carbons of the same section. The lime and the phosphoric acid were, however, diffused in the air, producing some smoke.

2°. The chloride of calcium, the borate, and the silicate, were also decomposed. But the boric and silicic acids seemed to escape the action of the electricity by volatilizing. The light was less than with phosphate of lime.

3°. Silica made the carbon worse conductors, and diminished the light; it also fused and was volatilized without being decomposed.

4°. Magnesia, borate and phosphate of magnesia were decomposed, and the magnesia vapour passing to the negative pole burnt in the air with a white flame, which much increased the light—less so, however, than the lime salts. Magnesia, boric, and phosphoric acid were diffused in the air as smoke.

5°. Alumina and silicate of alumina were difficult to decompose; a very strong current and a considerable arc were required. Under these conditions the aluminum was seen to issue in vapour from the negative pole like a jet of gas, and to burn with a bluish little—luminous flame.

Archereau found that the introduction of magnesia into the carbons increased their illuminating power in the proportion of 1.34 to 1.

According to Carré it would seem—

1°. That potash and soda doubled at least the length of the arc, rendered it silent, and, by combining with the silica always present in retort-coke, they eliminated it in the state of transparent, vitreous, and often colourless, globules at 6 or 7 millimetres from the points. The light was increased in the proportion of 1.25 to 1;

2°. That lime, magnesia, and strontia increased the light in the proportion of 1·30 or 1·50 to 1, giving it different colours ;

3°. That iron and antimony brought up the increase to 1·60 and 1·70 ;

4°. That boric acid increased the duration of the carbons by covering them with a glassy coating which protected them from the air, but without increasing the light ;

5°. That the impregnation of pure and regularly porous carbons by solutions of various substances is a convenient and economical means of producing their spectra, but it is preferable to mix the elementary substances with compound carbons.

Metallized Carbons.—According to E. Reynièr, the carbons being consumed a little by combustion on their lateral surfaces, which glow for a length of 7 or 8 millimetres above and below the luminous point, there is a complete loss as regards the light, and it would be an advantage to cover them with a metallic covering in order to avoid this lateral combustion. It follows, in fact, from his experiments in the workshops of Sautter and Lemonnier with a Gramme machine of the 1876 form, that the metallized carbons are consumed less than the ordinary carbons, as the following results show :—

Dimensions of the Carbons.	State of the surface of the Carbons.	Length of Carbons used in one Hour.			Photometric Measures in Carcel Lamps.
		At the + pol.	At the — pole.	Total.	Gas Jets
d = 7 mm. S = 0·3846 sq. cm.	Uncovered	166 mm.	68 mm.	234 mm.	947
	Covered with copper	146 "	40 "	186 "	"
	Covered with nickel	106 "	38 "	144 "	917
d = 9 mm. S = 0·6358 sq. cm.	Uncovered	104 "	50 "	154 "	528
	Covered with copper	98 "	34 "	132 "	553
	Covered with nickel	68 "	36 "	104 "	516

"These experiments," he says, "were made with Carré carbons and a Serrin lamp. It was observed that with naked carbons those of the smallest diameter had the longest points, as might have been expected ; but with the metallized carbons the reverse was the case, a circumstance difficult to explain.

"We may, however, conclude from these experiments :—

"1°. That independently of the improvement in the shape of the positive carbon, covering it with nickel lengthens the duration by 50 per cent. of the carbons of 9 millimetres, and by 62 per cent. that of the 7 millimetre carbons. Covering with copper also increases the duration by an amount intermediate between that of the naked and of the nickelized carbons ;

"2°. That with equal sections the metallization of the carbons does not seem to modify the amount of light yielded by them ;

"3°. That the luminous power of the carbons of small diameter is much superior for the same electric intensity to that of carbons of large diameter, which is explained by the fact that conducting bodies placed in a circuit composed of conductors of large section or of high conductivity become the more heated as their diameter is smaller ; and also from the fact of the polarization being the more energetic, the smaller are the carbons. This the more concentrates the resulting calorific effects of which we have spoken above. It depends also upon the circumstance, that to obtain the maximum of light it is necessary that the resistance of the circuit of the voltaic arc should be as nearly as possible that of the generator ;

"4°. That the metallization by allowing carbons of small instead of large section to be used for the same time of action, gave advantageous results. This metallization is effected galvanically."

According to A. Ikellmer, this system of metallization can have no advantage except in so far as it may lessen the resistance of the carbons, and as the thin layer of metal is oxidized by the influence of the high temperature and disintegrated for a distance that may reach as much as 10 centimetres, an improvement of the conductivity cannot in this way be obtained, any more than the prevention of lateral combustion. Consequently, he thinks that the problem

would be solved much better, at least so far as increased conductivity is concerned, by connecting with metallic rods. These rods may be placed either within the carbons themselves or in the electric candles on both sides of the insulator, and thus they may become heated without danger of oxidation. Jablochkoff, who had patented this system of rods as early as November, 1878, finds them advantageous only so far as they lessen the consumption of the electrodes; and if instead of a covering of carbon use is made of a covering of magnesia and an iron rod, as in the preparation of these candles, the consumption might be reduced to one-eighth. But this result is obtained at the expense of the brilliancy of the light produced, which is then reduced to that of six or eight gas-jets. Nevertheless, as there are cases where there is an advantage in increasing the duration of the candle at the cost of the luminous intensity, he has patented this system with the idea of using it in Russia for lighting carriages.

Effect of heat on the conductivity of the carbons.

—Heat is known to modify the electric conductivity of bodies, diminishing that of metallic conductors, and usually increasing that of substances of mediocre conductivity, whether liquid or solid;* and carbon is precisely one of these.

According to the researches of Borgman, the temperature of a carbonaceous substance heated to orange-red decreases its resistance in the following ratio:—

For wood charcoal	... ..	0'00370—	between 26° and 260°
For Dormez anthracite	... ..	0'00265—	„ 20° „ 260°
For Alibert plumbago	... ..	0'00082—	„ 25° „ 250°
For coke	... ..	0'00026—	„ 26° „ 275°

It would seem that even a feeble calorific radiation causes a diminution of resistance in plates of wood charcoal, and that between 100 and 125 degrees the resistance of pine-wood, elm, and ebony charcoals notably varies.

* See my Paper on the conductivity of mediocre conductors, p. 27.

Light produced by means of conductors of indifferent conductivity.—We have said at the commencement of this chapter, that one of the means of producing the electric light is the heating which takes place when a powerful current traverses a body of indifferent conductivity interposed between two electrodes of good conductivity. We have also seen that rods of carbon and of refractory substances constitute these bodies of indifferent conductivity, and that Jablochkoff on one hand, and Lodyguine and Kosloff on the other, had made some very interesting experiments on this subject. It is this new method of producing the electric light that we are now about to consider, and we shall begin by Jablochkoff's system, which is the most curious.

Jablochkoff's System.—In this new system the induction currents from a Ruhmkoff's coil of moderate dimensions are used, and a piece of slightly baked kaolin, two millimetres thick and one centimetre wide, which forms the semi-conducting substance, is required to supply the incandescent point, or rather the luminous source, for the whole appears to be illuminated. With a single coil two sources of light can easily be obtained in one circuit, but by increasing the number of induction coils and the power of the generator, the number of these luminous sources may be indefinitely increased—a circumstance which may in some degree solve the difficult problem of the division of the electric light. We shall, however, consider this question farther on.

The arrangement of the system is very simple; the small piece of kaolin is introduced between two little iron nippers which form the polar electrodes, and which are themselves attached to two clips capable of moving horizontally by means of a screw. These nippers seize the piece of kaolin by its upper slightly thinned edge, and even a little beyond this edge, in order that the apparatus may be more easily lighted; for this apparatus must be lighted, and it will readily be understood that the substance is not of itself sufficiently

conductive, even of induced currents, to be capable of passing a current able to produce the electric light. To remedy this defect of conductivity, the plate of kaolin must be warmed in the neighbourhood of the electrodes, and this is done in a very simple manner, by connecting the two iron clips mentioned above by a rod of retort carbon. By first taking a spark from one of the clips the carbon glows and transmits its heat to the neighbouring part of the kaolin, which fuses and affords a passage to the electric influence, at first through a very short space (1 or 2 millimetres), then over one progressively longer in proportion as the carbon is moved along the kaolin, and which at length occupies the whole length of the latter when the carbon has reached the second iron clip. The current then follows the track of fused matter which is progressively formed, and reveals itself to the eye as a band of dazzling light, appearing much wider than it really is on account of irradiation. Care must be taken to concentrate the heat developed by the carbon by means of a reflector of refractory matter, which may consist of a plate of kaolin. The light thus supplied is, as I have already said, very steady, very brilliant, and much softer than the arc light. Its power depends, of course, on the resistance of the circuit and on the number of luminous points interposed, but with a weak electric force it is equal to one or two gas-jets.

Kaolin appears to be the best substance, because, being prepared as a paste, it can be made very homogeneous; but other substances are capable of producing the same effects; magnesia and lime have indeed given very good results.*

* The conductivity of this kaolin, studied by means of the process used in my researches on substances of mediocre conductivity, showed traces of the passage of the voltaic current produced by 12 Leclanché elements only when the specimen had remained in a cellar for more than a day. When it was kept in an inhabited apartment it gave no deviation, and when it was heated to redness in a spirit-lamp it gave a deviation of only 1 degree. It is therefore necessary in order to obtain the important effects that have been mentioned, that the electricity of tension should, in consequence of the resist-

A very interesting circumstance was discovered in the experiments made by Jablochhoff, and that is, that the currents supplied by the induction apparatus intended for the light are most advantageously exerted by a magneto-electric generator giving alternately reversed currents, such as those supplied by the *Alliance* Company or the *Lontin* Company. With such a generator, the induction apparatus does not require either a condenser or an interrupter, and the intensity of the current is increased by the suppression of these. On the other hand the tension is notably diminished, for in experiments I have witnessed, the spark was hardly 2 millimetres long; but in order to obtain calorific effects, tension is specially necessary, and we have seen that in this respect the results have left nothing to be desired. Thanks to this plan, a Ruhmkoff induction machine can supply the electric light, and this result is of the more importance that a regulator of the light is not required to render it steady, and that the consumption of kaolin is almost insignificant (1 millimetre per hour). The magneto-electric generator itself need not be powerful, and it may, as we have already said, be proportioned to the number of luminous jets desired, care being taken to connect a suitable number of induction coils having their induced wires not too thin.

When the illumination of a long strip of kaolin is required under the influence of a very powerful current, it becomes necessary in order to light it to mark a line of lead on the upper edge of the bad conductor from one electrode to the other. The current is at first conducted by this streak, but is not long in heating the kaolin and in producing the effects we have described. This arrangement enables a large quantity of light to be obtained in a small space, for in order to increase the effect it suffices to fold the strip several times on itself like an electric multiplier.

ance it meets in its passage, be accumulated within the very substance of the bad conductor, and should be transformed into heat by not being able to flow away fast enough as an electric charge.

According to Jablochhoff, the luminous intensity of these different sources varies according to the arrangement and dimensions of the coil, and the number of lights interposed in the circuit of each coil. They may therefore be so arranged as to supply light of different intensities from their minimum light of 1 or 2 gas-jets up to a light equivalent to 15 jets.

"In this system," says Jablochhoff, "the method of distribution of the circuits is in fact reduced to a central artery represented by a series of anterior wires corresponding with the inducing helices of the different coils, and with as many *partial circuits* as there are coils; these last circuits corresponding with the induced wires of the coils, and ending separately at the different luminous foci which are to be maintained. Each of these foci is therefore perfectly independent, and can be extinguished or lighted separately. Under these conditions the distribution of the electricity becomes very similar to that of gas, and I have been able to have 50 foci simultaneously illuminated with different intensities."

Jablochhoff has lately rendered more practical the system we have just described by causing the current supplied by the small pattern of the magneto-electric *Alliance* machine to act directly. In order to impart more tension to the currents he adopts a condenser of rather large surface to one of the wires going from the machine to each apparatus. This condenser is composed of sheets of tinfoil, india-rubber, and varnished silk, alternated and folded as in the English condensers for submarine cables. In this way, with a total condensing surface of 200 square metres, seven points of light may be obtained instead of two, and what is more curious, the increased effect is produced even with currents alternately reversed. The arrangement of this system is besides very simple; one of the armatures of each condenser is connected with one of the two wires of the machine, and the second wire of this machine is connected with one of the clips of each light apparatus, while the other clip corresponds with the second armature of each condenser. There is then produced within each condenser successive fluxes of each

kind of the contrary electricities, which, by charging the condensers, cause the illumination of the plates of kaolin, on which streaks of black lead extend from one clip to the other.

Lodyguine and Kosloff's System.—Of the various methods used for obtaining luminous effects by the narrowing of the section of a good conductor, that contrived by Lodyguine and Kosloff had given some very interesting results. These results even made some noise in 1874, for the effects were nearly similar to those we have just mentioned; but in order to produce them a much greater electrical force was required, and the portions of the apparatus brought to a white heat, being made of retort-coke of very narrow section, did not present the desired conditions of solidity and stability.

In this system these little needles of carbon were cut out of carbon prisms of at least 1 centimetre across, and were fixed between two insulated clips connected with the two branches of the circuit, as in Jablochkoff's system.* In order to prevent their combustion they were enclosed in vessels free from air, or simply hermetically sealed, so that the oxygen of the enclosed air should not be renewed. With a powerful *Alliance* machine four luminous foci could, it is said, be obtained in this way, and the lighting power was very satisfactory. Unfortunately these carbons were frequently broken, and it was quite a task to replace them. To obviate this inconvenience several ingenious arrangements were invented, of which we shall speak farther on; but all these systems have scarcely yielded anything very satisfactory from a practical point of view.

The slender rod of carbon was in fact consumed parti-

* It seems that the connection of the carbons intended to become red hot with the wires of the circuit was one of the difficulties which checked Lodyguine and Kosloff. In fact, by making the wire penetrate into the carbon, the latter was broken, on account of the difference of the expansion of the metal and that of the carbon, and again the metal by touching the parts of the carbon heated to whiteness was melted. Kosloff, after many experiments, has, it appears, avoided these difficulties by using a special metal to form the supports of the carbon rods.

cularly in the middle, and it was observed that the residue showed a notable part of the carbon to have been ignited, hence a considerable loss in the strip of carbon.

Edison's System.—In the year 1845 Draper had endeavoured in America to take advantage of the incandescence of a platinum wire, rolled in a spiral form, as a focus of electric light, and in 1858 there was much said of a system invented by De Changy, which was merely the same thing.* Latterly Edison has taken up the notion, and has made noise about it in the newspapers great enough to lower very considerably the shares of the gas companies. But this system, besides lacking novelty, only very imperfectly solves the problem, and in the chapter on incandescent electric lamps will be seen the means he used, not to produce the electric light, for everybody knew that, but to prevent the platinum spirit from melting when the intensity of the heat exceeded the melting point of platinum.† Hospitalier has also invented a kind of regulator for the same purpose, but it is more complicated, and makes the apparatus a sort of incandescent electro-magnetic lamp. We think that all these methods of electric lighting founded solely on the effects of incandescence leave much to be desired, and we

* In the *Comptes rendus de l'Académie des Sciences de Paris*, 27th Feb., 1858, it will be seen that Jobard, of Brussels, had announced to the company that De Changy had just solved the problem of the divisibility of the electric light by help of the incandescence of platinum spirals. (See my *Exposé des applications de l'électricité*, t. IV., p. 501, 2me édition.)

† It appears, according to some American newspapers, that the pretended marvellous discovery of Edison is not serious. Here is what we read in the *New York Herald* of 5th Jan., 1879:—Mr. Edison has received from the Electric Light Company 100,000 *livres* in order to continue his experiments. He has already spent, it is believed, 76,000 *livres* up to the present time, and he has yet produced nothing but promises; but it may be taken as certain that none of these will be fulfilled, and that no important revolution as regards the electric light will come from Menlo Park for the next 50 years, at least if one may judge by the present rate of progress. What will be done there will depend in a great measure on the conclusions arrived at after all the researches and experiments conducted in the whole world, the results of which are continually sent to Mr. Edison.

believe those to be preferable in which combustion and the voltaic arc are united to incandescence. We shall see that in the systems of Reynier, Werdermann, &c., the results are in fact much more satisfactory.

Systems of É. Reynier, Werdermann, and others.—By the beginning of the year 1878 Émile Reynier, struck by the advantages which incandescent effects offered for the ready production of the electric light, and especially for its subdivision, bethought himself of combining these advantageous effects with those of the voltaic arc, and for that purpose he arranged the carbons of the King or Lodyguine system in such a manner that they might burn and furnish at the point of contact a small voltaic arc resulting from the repulsions produced by contiguous elements of the same current, as in the case of Fernet's and Van Malderen's regulators. He therefore arranged above a large fixed carbon a very slender rod (about 2 millimetres diameter), which was supported vertically by means of a heavy holder, and he connected this carbon with the current at a suitable height above the fixed carbon, so as to give a bright incandescence to the thin carbon. And by this arrangement as the thin rod of carbon was consumed at the point of contact with the large carbon, it was renewed by a progressive advance produced by the weight of the holder. From this combustion, however, ashes were produced, which accumulated round the point of contact, and therefore he arranged the apparatus so that the large carbon might by a rotatory movement cause the ashes to fall off. Under these conditions Reynier was able to light 5 lamps with the current from a Bunsen battery of 30 cells, and he was even able to keep one of the lamps lighted for more than a quarter of an hour with the current from a Planté polarization battery of 3 elements. Some time afterwards the same idea was taken up by Werdermann, who used an arrangement the reverse of Reynier's. The stick of carbon was pushed upwards by a counterpoise, and thus the large carbon did not require to be moved. According to

him this plan gave very good results, and with an electroplating Gramme machine arranged for quantity he was able to light in 10 derived circuits 10 lamps of this kind, each giving a light equal to 40 candles.* The experiment he made on this occasion on the influence exerted by electrodes of carbons of different diameters, being very interesting as regards the present question, we here give them from a paper presented to the *Académie des Sciences* on the 18th November, 1878 :—

“When the electric arc is produced between two carbons of the same section,” says Werdermann, “the changes in the polar extremities take place thus : the positive electrode heated to whiteness takes the shape of a mushroom, is hollowed into a crater form, and is consumed twice as fast as the negative electrode. The latter, which is only heated to redness by the current, is then slowly shaped into a point, and the length of the arc is in proportion to the tension of the current.

“Things do not pass thus if a different section is given to each electrode. When the section of the positive electrode is gradually lessened, and that of the negative electrode increased, the red heat seen at the point of the latter diminishes more and more, whilst the heat of the positive electrode increases in proportion to the reduction of the section. The electric current no longer passes over the space between the electrodes with the same facility, and in order to maintain the voltaic arc the electrodes must be brought nearer together.

“A strange phenomenon then appears ; the end of the positive electrode enlarges considerably, and the current shows a tendency to equalize the two surfaces, that is to say, to give to the positive electrode as much as possible the same section as the negative. The greater the difference between the sections of the carbon, the more must the distance between them be lessened ; and to avoid too great a swelling of the positive electrode the tension of the current must be a little reduced, which is easily done by using a Gramme machine, with which the tension of the

* According to Werdermann, the machine required only 2 horse-power to yield this light. But I am informed that this is incorrect, and that a much greater force must be taken into account.

current is proportional to the speed, the resistance of the coil being constant.

"We thus reach a limit where the distance between the electrodes becomes infinitely small, that is to say when the electrodes are in contact. This is when their sections are nearly as 1 to 64; then the negative electrode scarcely gets heated, and it is therefore not consumed. Under these conditions it is only the positive electrode which is consumed, while it produces a beautiful absolutely fixed white light so long as the intimate contact between it and the negative electrode is maintained. It is in reality a light produced by an infinitely small voltaic arc.

When the reverse method is adopted, that is to say, when, instead of lessening the section of the positive electrode, the section of the negative is gradually reduced, and the section of the positive increased, the light of the latter is seen to gradually diminish, and the heat of the negative electrode to increase.

"When the sections of the electrodes are nearly as 1 to 64, and they have been placed in contact, no light is any longer given off by the positive electrode; the negative one alone produces the light. It is curious that when a voltaic arc is set up between the two carbons, the smaller electrode is always shaped into a point, whether it be positive or negative."

Fig. 37 represents the series of changes in the form of the electrodes when their respective dimensions are made to vary. The electrodes in the centre represent the ordinary electrodes of equal section. In the three systems on the left are shown the effects produced as the lower electrode, which is the positive one, increases, and the three on the right show the effects of a successive increase of the upper and negative electrode.

As we have seen, Werdermann has been able by derivation to obtain with an electroplating Gramme machine the lighting of 10 electric lamps. The resistance of the coil of the machine was 0.008 ohm, and the electro-motive force was equal to that of 4 Daniell cells, with a speed of 800 turns per minute. At this speed the current corresponded with 66.06 webers; but with a speed of 900 turns it corresponded

with 88.49 webers. Nevertheless, with the 10 lamps arranged by Werdermann the velocity of 800 turns was sufficient.

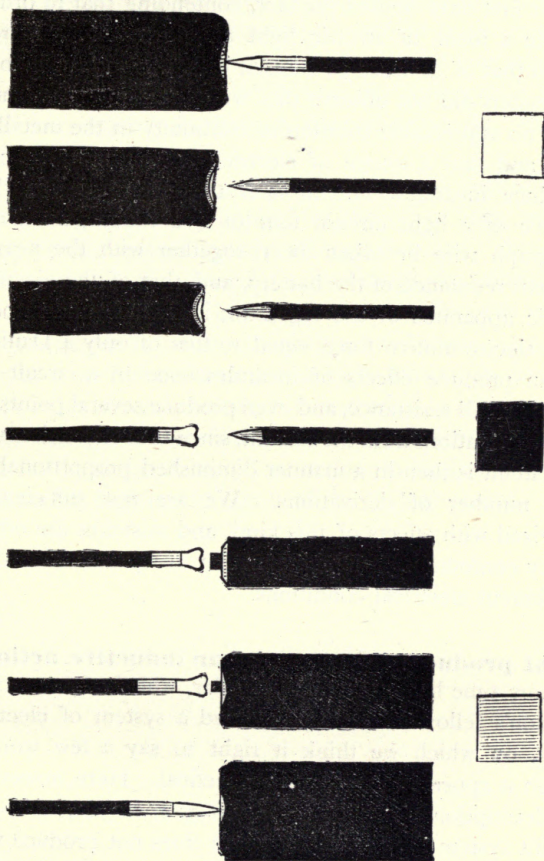


FIG. 37.

According to Werdermann, the resistances of the circuit were :—

For one lamp ...	...	...	...	...	0.392 ohm
For five lamps ...	...	...	...	...	0.076 „
For six lamps ...	...	...	...	...	0.037 „

It is surprising that with a current having so little tension such results could be obtained, and some sceptical persons would at first have denied the fact, contending that in order to obtain a focus of electric light an electro-motive force equal to that of at least 30 Bunsen cells was required ; but such persons did not observe that with incandescent lamps there is no appreciable solution of continuity in the metallic circuit, and that a source of electricity of quantity suffices to produce incandescence in such a circuit. If from the resistance of a light circuit, four or five thousand metres of telegraph wire be taken away, together with the nearly equivalent resistance of the battery, and that of the electro-magnetic apparatus of the regulator, it may be understood how an electro-motive force equal to that of only 4 Daniell cells can produce effects of incandescence in a circuit of extremely small resistance, and even produce several points of light, by derivations from the current, since the total resistance of the circuit is then in a manner diminished proportionably to the number of derivations. We are not sufficiently familiarized with effects of this kind, and mistakes are often made by confounding phenomena that are produced under very different electrical conditions.

Light produced by means of an inductive action.

—A short time before his death, Fuller, who had been one of Edison's fellow labourers, invented a system of electric lighting, on which we think it right to say a few words, although it appears to us scarcely practical. Here, however, is the description of it given in the *Telegraphic Journal* :—

In this system the principal current does not produce the light, but it engenders another current in a series of induction coils, and each lamp is lighted by the current of one of the coils. An alternating current must be used. The induction coils were constructed as follows:—Two magnetic cores, placed parallel to each other, were magnetically connected at one end. Round the centre of each of these cores was a

head of soft iron, and at a suitable distance a head of insulating substance. The external extremities of the cores were covered with insulated copper wire, and were connected together, as well as to the principal wire (or to the generator), in such a manner as to produce two opposite magnetic poles. Between the soft iron heads and the coils spirals of finer wire were wound, the fineness depending on the tension required.

To one of the iron heads an iron arm was jointed capable of turning and being applied to the other head, and thus magnetically connecting the N. and S. poles. In a system thus arranged, if a current is sent through the principal wire, and quickly reversed in the opposite direction, the polarities of the magnetic cores will change, and these changes will produce an induced current of high tension in the smaller coils; this second current, if it is carried to a lamp by suitable wires, will maintain the carbon or platinum in a high state of incandescence. Two or four induction coils may be connected together for lights of the highest power.

PART III.—ELECTRIC LAMPS.

IN order to obtain a continuous action from the carbons used for the electric light, these carbons must, in proportion to their consumption, be brought near each other, so that the intensity of the current may be kept as constant as possible. Now in order to obtain this result, arrangements have been contrived which effect it automatically, and these form what are called *regulators* of the electric light, or simply *electric lamps*. Of course the construction of these apparatus varies according as the light is produced by the voltaic arc or by incandescence.

VOLTAIC ARC LAMPS.

Electric lamps are of an earlier date than is generally supposed. In 1840 they consisted of a kind of Lannes exciter, the balls of which were replaced by sticks of carbon, which were pushed forward by hand as they were consumed, and the apparatus had the form represented in Fig. 1. A little later an attempt was made to render the forward movement of the carbons automatic by placing the holders under the control of clockwork, or of electro-magnetic effects, which could act as a balance, that is to say, on the least variation in the intensity of the current. Then the idea was conceived of arranging the carbons so as to burn like a candle, and it is to this last plan that recourse has been had in the attempts at electric lighting of the streets, which so astonished visitors during the whole period of the Exhibition of 1878.

The first automatic electric lamp appears to have been invented in 1845 by Thomas Wright; but it was not until 1848, when Staite and Petrie, in England, and Foucault, in France, invented their regulators that attention was attracted to the matter; and before these apparatus could be regarded as capable of any practical application, Archereau on the one hand, and J. Duboscq on the other, had used them for numerous experiments in projection. From that time, and especially after the curious results obtained by the machines of the *Alliance* Company, people began everywhere to apply themselves to the improvement of these apparatus, and a multitude of systems were invented, the most important being those of Serrin, Duboscq, Siemens, Carré, Lontin, Rapieff, Brush, &c. Having in the 5th vol. of my *Exposé des applications de l'électricité* described most of these numerous systems, I shall here concern myself only with those that have become common in practice.

Regulators of the electric light may be divided into six classes, viz. : 1°. regulators founded on the attraction of solenoids, and to this class belong the regulators of Archereau, Loiseau, Gaiffe, Jaspar, Carré, and Brush; 2°. regulators founded on the approximation of the carbons by successive movements produced electro-magnetically, and among these we may mention the regulators of Foucault, Duboscq, Deleuil, Serrin, Siemens, Girouard, Lontin, Mersanne, Wallace Farmer, Rapieff; 3°. regulators with circular carbons, the most important types being the regulators of Thomas Wright, Lemolt, Harisson, and Reynier; 4°. regulators with a hydrostatic action, amongst which we may name those of Lacassagne and Thiers, Pascal, Marçais and Duboscq, Way, Molera, and Cebrian; 5°. reaction regulators, such as those of Fernet, Van Malderen, and Bailhache; 6°. electric candles on the Jablochkoff plan, and others. The incandescent carbon regulators forming a class by themselves, we shall discuss farther on.

Of all these apparatus, those of Foucault and Duboscq,

Serrin, Gaiffe, Siemens, Carré, Lontin, Rapiéff, Brush, and Bürgin are the only ones which are practically used, and therefore we shall describe the details of these only.

Foucault and Duboscq's Lamps.—Foucault was, as we have seen, one of the first to invent the regulator with a fixed luminous point working by successive electro-magnetic movements. He thus describes his apparatus to the *Académie des Sciences*:—

“The two carbon holders tend to move towards each other by springs, but they can only move by setting in motion a train of wheels, the last of which is controlled by a catch. It is here that electro-magnetism comes into play; the current that lights the carbons passes through the spires of an electro-magnet with an energy varying with the intensity of the currents. This electro-magnet acts on a piece of soft iron drawn away on the other hand by an antagonist spring. On this piece of soft iron is mounted the detent which engages the wheel and allows it to pass when necessary, and the direction of the movement is such that it presses on the wheel when the current becomes stronger, and liberates it when the current becomes weaker. Now, as the current becomes stronger or weaker precisely when the interpolar distance decreases or increases, it will be understood how the carbons have the power of approaching at the instant the distance between has just been increased, and that this approach cannot proceed to actual contact because the increasing magnetization resulting from it opposes an insurmountable obstacle, which rises of itself as soon as the interpolar distance is again lessened.

“The approach of the carbons is therefore intermittent; but when the apparatus is well adjusted, the periods of rest and of advance succeed each other so rapidly that they are equivalent to a continuous progressive movement.”

Foucault does not explain how he adjusted the greater or less approach of the carbons; it was probably by giving the

pulleys over which passed the cords that moved the carbons an unequal diameter proportional to the amount of the consumption. Nor does he describe the way in which the detent acted; but it seems from his description that it was merely by a simple pressure against a drum fixed on the axle of the two pulleys, on which were wound in opposite directions the cords attached to the carbon-holders.

Be that as it may, this apparatus has been the starting point for all those we are about to mention, and which require a definite place for each pole of the battery.

Some years after the apparatus just

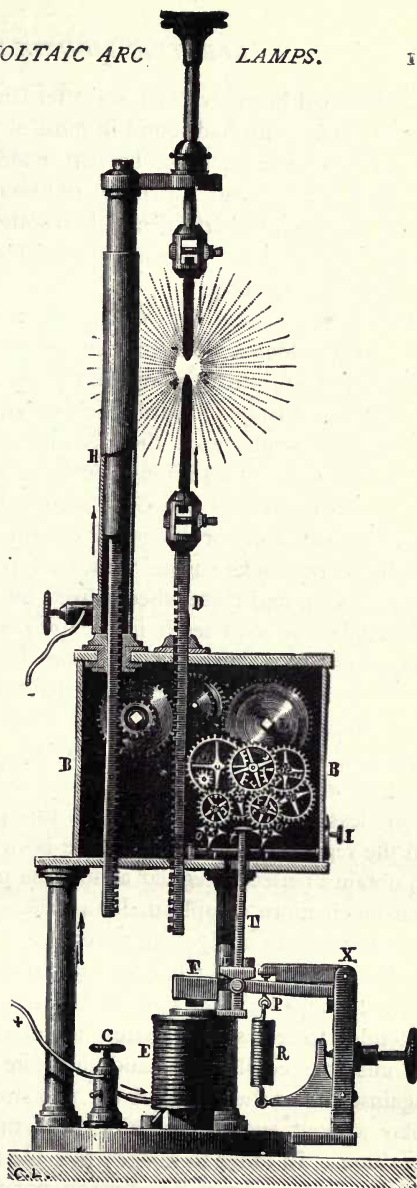


FIG. 38.

described had been invented, and after Duboscq had pointed out the defects he had found in most of the regulators then in use, and even in those he had made himself, Foucault invented a new form which we represent in Fig. 38, and which has been hitherto generally resorted to for all experiments of projection. This is the model which has been constructed by J. Duboscq.

In this new system the carbon-holders B and D end below in racks on which a clockwork movement acts by means of a double wheel, which is arranged in such a manner that the two carbons advance towards each other, and the lower one D moves through twice the distance that the upper one passes through. This arrangement was governed by the unequal consumption of the two carbons, which, as shown on page 20, is double for the positive carbon. To obtain this result, the two racks engage with the two wheels of which we have spoken, and these wheels, fixed on the same axis, have the number of their teeth in the proportion of 2 to 1. To cause this arrangement to act upon the carbons, it is only necessary so to contrive matters that when the intensity of the current becomes a little too feeble an electro-magnet shall act on the clockwork, and that its action shall be stopped when, by the approach of the carbons, the voltaic arc offers less resistance. It is upon this principle that nearly all the regulators of this class have been based; but in order to obtain a perfectly regular action, the problem to be solved was much more complicated, and the special arrangements we have now to study were necessary.

The defect of the regulators founded on the principle we have explained above, was that the electro-magnet armature intended to release or to arrest the clockwork was in a state of unstable equilibrium, and therefore liable to be driven against one or the other of the two stops which limited its play without ever being able to remain in an intermediate position. In order to remedy this, the antagonistic spring R of the electro-magnet E was made, not to act directly on the

armature, but on the extremity *p* of a piece jointed to a fixed point *x*, and having its edge shaped to a particular curve, and in rolling pressing on a projection, which thus represents a lever of variable length, as in *Robert Houdin's electric distributor*. The armature must then always remain thus fluctuating between the two limiting positions, for at each moment the antagonistic force opposed by the spring to the attraction of the electro-magnet is compensated by the effect of the lever thus arranged. Or in other words, the position of the armature every instant expresses the intensity of the current. Whilst the intensity preserves its desired value, which is co-relative to the distance maintained between the carbons, the armature is balanced in such a manner as to prevent any movement of approach or recession; the moment the current becomes too strong or too weak, there is a recession or approach, for the lever *r* attached to the branch of the armature lever *p* produces these effects by the oscillation of an escapement anchor *t* fixed at the end of the lever *r*, which engages and disengages a double clockwork mechanism, the action of which we shall now study. In this, the fly vanes *o* and *o'* act as detents.

This mechanism represented on a larger scale, in Fig. 39, is set in motion by two spring barrels *L L'*, each of which controls its own trainwork of wheels, the last piece bearing the fly vane mentioned above. The system controlled by the barrel *L* tends to separate, and the other to bring them together; but in order that these mechanisms working in opposite directions may act on the movers of the carbons, a special mechanical contrivance was necessary, and Foucault had recourse to an arrangement invented by Huyghens, consisting of two *sun and planet* wheels *f* and *e*, fitted to a wheel *s*, which rotates on the axle *gh*. It is this wheel which governs the motion of the double wheel acting on the racks *h* and *d*; but it can come into action only when the wheelwork in connection with the flies *o o'* is liberated by the electro-magnetic effect and the movement of the detent *t*. When in con-

sequence of the liberation of the fly *o'*, the wheelwork *c d* is allowed to act, the barrel *l'* makes the wheel *S* turn in the direction of the arrow, and the two carbons are brought

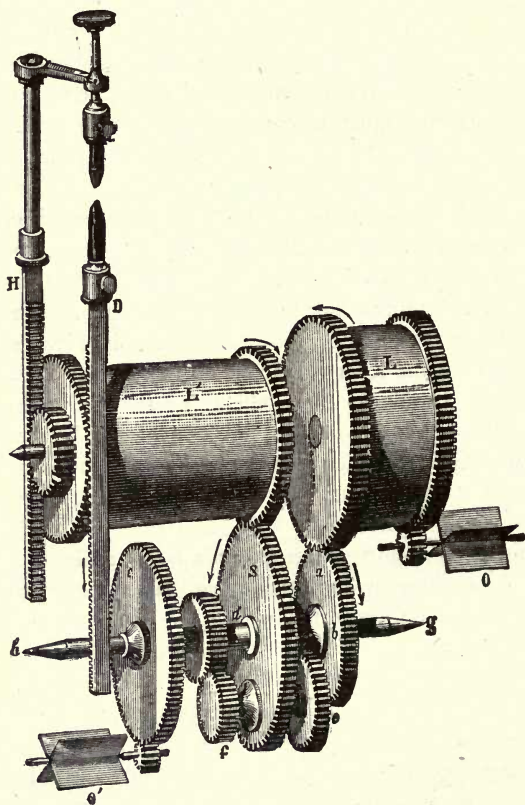


FIG. 39.

nearer together. At the same time, the two sun and planet wheels are turned, but without producing any effect, for they revolve round the wheels *h* and *d*; but when the second fly *o* is liberated the planet wheel *e* is set in motion by the wheel *a* and the pignon *h*, and by acting through the planet

wheel *f* on the wheel *d* it compels the wheel *S* to move a little in the direction opposite to the former. But to effect this it is necessary that the barrel *L* should have as much power as *L'*. In any case the motion can only be very small. The wheels *a* and *b* must be of one piece, but they must move with gentle friction on the axle *gh* in order that the wheel *S* may turn with making them share its motion. If this much has been understood, it only remains to examine the mode of action of the apparatus.

The arc being established between the two carbons, the attractive action of the electro-magnet is counterbalanced by the antagonistic spring, so that only one of the arms of the escapement anchor engages the fly *o'*. As the carbons consume, the armature *F* is the less attracted the more the arc is lengthened, but no sudden movement occurs; the armature drawn away by the spring rolls on the jointed curve *x*, Fig. 38, and at last the hammer liberates the fly *o'*, and engages the fly *o*; the carbons are then approximated until the intensity of the current is sufficient to re-establish the power of the electro-magnet. If the carbons are too near, the armature *F* is attracted the more, and the escapement anchor will set free the fly *o*, which will cause a separation of the carbons.

Let us add, that the carbons are capable of being moved in two ways by hand in order to fix the position of the luminous point in the first instance. Thus, the upper carbon may be moved independently of the lower one, the whole system may be raised or lowered, the separation of the carbons continuing unchanged; and this is required for properly centring the light in projections.

An important improvement has lately been made in this apparatus. It had been found that changes in the intensity of the current modified the condition of the magnetic core, and that the magnetic power persisted more or less. The antagonistic spring regulated by a screw, seen on the right in Fig. 38, was therefore unable for a given electric intensity to

maintain the equilibrium, and if too great a tension were given to it the movement of the apparatus became too jerky.

This inconvenience has been got rid of by so arranging the armature, to which a curved form is given, as to vary its distance from the poles of the electro-magnet. This motion is produced by the friction of an eccentric lever. This slight modification is shown in Fig. 40, which represents the external appearance of the apparatus. As the least variation sensibly alters the effective power of the attraction, the action of the electricity may then be easily and very exactly regulated, according to the power of the electrical generator at a given instant.

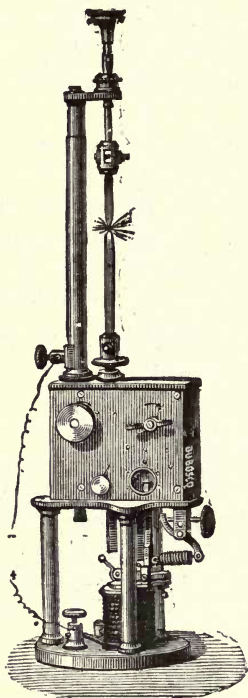


FIG. 40.

In this new model the positive pole may be placed above or below as required. The + pole should correspond with the upper carbon for lighting purposes, and with the lower carbon for optical experiments, such as the combustion of metals, &c.

"This new regulator," says Duboscq, "fulfils all the conditions required for the application of the

electric light to scientific experiments, and to the illumination of lighthouses, vessels, workshops, theatres, &c.

"In the present state of science the electric light is as commonly produced with the magneto-electric machine as with the battery; it may even be affirmed that the *industrial generator* of the electric light is magnetic action: witness the electric lighting of lighthouses, ships, yards, &c. It was therefore

requisite to make the regulator suitable for these two sources of electricity. When the arc that springs between the carbons is derived from the battery, they are consumed in the ratio of 1 to 2; if, on the other hand, it is derived from the magneto-electric machine, the consumption of both carbons is alike, since the currents are alternating. In the former case it is necessary to arrange the advance of the carbons in the ratio of 1 to 2, and in the latter to make it equal. An addition to the mechanism enables the change of the relative velocities of the carbons to be made in an instant, according as one or the other source of electricity is made use of.

“Thus improved, the new regulator is perfectly adapted to all the applications of the electric light.”

Serrin's Lamp.—Of all the regulators yet invented, that of Serrin is the one most used when a prolonged illumination is required. We have had the pleasure of following the various phases through which this apparatus has passed since its invention, and we were the first to give a complete account of it in *tome IV.* of the second edition of our *Exposé des applications de l'électricité*, published in 1859. At a later period, Pouillet, in a report made to the *Académie des Sciences*, explained its ingenious arrangements. Finally, the experiments made with the machines of the *Alliance Company* showed that it was then the only apparatus that could work with currents alternately reversed. Since that period this regulator has been constantly used in the various experiments that have been made with the electric light, and it is the one adopted in the illumination of lighthouses. We must therefore dwell a little on this ingenious apparatus, which is so sensitive that an india-rubber ring placed between the two carbons is sufficient to arrest their progress without the ring losing its shape.

This apparatus, which is able, like that of Duboscq, to keep the luminous point stationary, is essentially formed of two mechanisms mutually connected, but each producing its own effect on the movement of the carbons. One of these

mechanisms, in direct communication with the electro-magnetic system, forms an *oscillating system*, composed of a kind of double jointed parallelogram, to which are attached the tube and accessories belonging to the lower carbon. It is formed of four parallel horizontal arms, turning on the tube of the upper carbon-holder and connected together by two vertical cross pieces.

The other mechanism, which we shall call *the advancing mechanism*, is connected with the carbon-holders, and is formed of wheelwork, together with a rack and draw chain. The first mechanism, while acting, as we shall see, directly on the lower carbon-holder, controls the action of the second mechanism; and this last, by rendering regular the approach of the carbons towards each other, carries out the mechanical effect begun by the first. With this object, the tube belonging to the lower carbon and forming part of the oscillating system, carries a stop of triangular shape which acts on the wings of a fly, forming the last moving piece of the advancing mechanism. The oscillating system connected by the two vertical cross pieces carries a cylindrical armature, which being placed within the influence of an electro-magnet acting tangentially on it, can more or less lower it according to the intensity of the current traversing the system. There are two opposing springs fixed to the lower arms of the oscillating system, and these springs are attached to the supports of the wheels; and raise the system when the current does not act with energy sufficient to counteract their effect. It follows therefore from this arrangement that, with an adequate electrical intensity, the oscillating system is sufficiently lowered to arrest the advancing system, and with an inadequate intensity this last system, being set at liberty, allows the carbons to approach each other merely by the effect of gravity on the upper carbon-holder, which is heavy enough to produce the movement of the system. Let us now see how the advancing system is arranged.

In the first place, it is formed of a set of four wheels, the

first of which engages a rack, making part of the upper carbon-holder, and has its axle provided with a drum, round which is wound a Vaucanson chain; this chain, after having passed over a pulley, is attached to a piece connected with the lower carbon-holder. It follows that when the oscillating system, in consequence of the inactivity of the electro-magnet, has liberated the wheel, the upper carbon-holder is free to descend, and in descending not only causes all the wheels to turn, but also raises, by means of the Vaucanson chain, the lower carbon-holder. This action goes on until the current, by becoming stronger, produces a more powerful action on the electro-magnet, which thereupon engages, by means of the oscillating system, the fly in the train of wheels. The apparatus is then stopped until the energy of the electro-magnet again diminishes. A second opposing spring, acted on by an adjusting screw, allows the sensitiveness of the instrument to be increased or diminished at pleasure. Lastly, a chain hanging down is so arranged as to act as a counterpoise to compensate, in the action of the oscillating system, for the loss of weight occasioned by the consumption of the lower carbon.

The current is transmitted to the lower carbon through a bent flexible plate which follows the carbon in its movements, and it is transmitted to the upper carbon through the mass of the apparatus and the electro-magnet which has the free extremity of its coil connected with an external binding screw.

There is nothing special about the lower carbon-holder: it is merely a socket provided with a pressure screw for holding the carbon; but the upper carbon-holder is more complicated, in order that it may have two rectangular movements so as exactly to fix the two carbons in the desired relative position. The positive carbon is maintained above the negative by means of a tube, supported by two horizontal jointed arms controlled by two screws. One of the screws allows the carbon-holder to be displaced in one vertical

plane, and the other, by means of an eccentric, displaces the carbon in the vertical plane perpendicular to the former.

Serrin has made several patterns of his regulator to suit the greater or less electric intensities that are to act upon it. His largest pattern is arranged to burn carbons of 15 millimetres broad, or 225 square millimetres in section ; and, in spite of these large dimensions, it is as sensitive as the smallest patterns. In the pattern made for lighthouses, the inventor has made several important modifications. Thus, by means of a little arrangement adapted to the chains of the carbon-holders, he has been able to shift the luminous point to a certain extent without putting out the light. This is very important in the application of these apparatus to lighthouses, for it gives the means of correctly centring the light with regard to the lenses.

Again, as these regulators have to act with extremely powerful currents, the heat in the circuit would be sufficient to burn the insulating covering of the coil in the electro-magnet, and thus destroy its effect. Serrin has made the electro-magnetic spirals with metallic helices unprovided with insulating covering, and so arranged that the spires cannot touch each other. In order that these helices might be adapted to the magnetic cores and to the discs of the electro-magnet with a sufficient insulation, he has covered these cores with a somewhat thick layer of vitreous enamel, as well as the inner parts of the discs ; and in order to obtain as many spires as possible with the maximum of section, he has cut these helices from a copper cylinder of a thickness equal to that of the coils. In this way the electro-magnetic helices are represented by a kind of close screw thread of a projection equal to that of the discs, and having its central part represented by the magnetic cores and the covering of enamel.

It will easily be understood that with this arrangement the helices may be carried to a very high temperature without the spires ceasing to be insulated from each other, for they are not in contact, and they are separated from the body of the

electro-magnet by a substance which cannot be changed by the most elevated temperature. Besides, the large section of the spire; thus formed makes the heating more difficult than with ordinary arrangements, and that is not one of the least advantages of this kind of electro-magnet.

I ought, in justice, to state that previously to Serrin an electro-magnet of this kind had been invented by Duboscq for his regulator, but he had not taken care to enamel the parts in contact with the helices, considering that precaution as useless, on account of the great section of the spires of the helix, which prevented them from being raised to redness. Nor did he form his spires in the same way: they were simply a strip of copper hammered into a spiral.

Siemens' Lamp.—The last of Siemens' lamps, which is much used in England and in Germany, is represented in Fig. 41. Like that of Serrin, it can be lighted automatically, and the two opposite actions required for the separation and approach of the carbons are determined by the weight of the upper carbon-holder and by the electro-magnetic vibration of a rocking lever which acts on a clockwork mechanism driven in the opposite direction by the weight of the carbon-holder. This mechanism, composed of four wheels, is arranged nearly as in the regulators we have just described, and it is on the last wheel 1, furnished with a ratchet and a fly with wings, that the vibrating electro-magnetic acts. This last is formed of a bent lever L, jointed at Y, and carrying at M the armature of the electro-magnet E. This is the principal organ of the apparatus, for on one side it carries a contact piece which forms with the stud X the vibrating circuit-breaker, and in the second place the antagonistic spring of the system, the tension of which is regulated by means of the screw R, and finally the driving and stopping catch Q, which acts on the clockwork mechanism by means of the ratchet wheel 1. A fixed piece S supports the end of this catch, in order to liberate the wheel 1, at a suitable inclination of the

lever L. Finally, a screw K, which passes through the case of the lamp, allows the distance of the armature to be properly adjusted to the current employed, and a small addition N, which also projects from the case, shows whether the electro-magnetic system is properly vibrating. The wire of the electro-magnet E is moreover connected with the mass of the apparatus, in order that the current which passes through and illuminates the carbons may be derived through the circuit-breaker at each attractive movement of the armature, and produce the vibration of the lever L by closing a short circuit.

The action of this apparatus is very simple. When a current passes through the electro-magnet E, the catch Q is withdrawn from the wheel I, and the upper carbon-holder, by weighing on the wheels of the clockwork, sets them going until the carbons guided by racks engaging these wheels are brought into contact. But if under these conditions the generator is put into communication with the lamp by the binding screws z and c, the current traverses the electro-magnet E, the mass of the apparatus, the upper carbon-holder, the lower carbon-holder, and returns to the generator by the communication connecting this with the binding screw z; the carbons then glow at their point of contact, the electro-magnet becomes active, and the catch Q, by acting on the ratchet wheel I, causes it to advance one tooth, by which the carbons are separated. But in this movement a contact is set up at x between the lever and the screw c, and the current, finding less resistance in passing by that path than through the electro-magnet E, in a great measure leaves the latter; then the armature, being no longer sufficiently attracted, causes a backward movement of the lever L, which again withdraws the catch Q, destroys the contact at x, and brings about a new attraction of the armature involving a new movement of the wheel I; and as these alternating motions are more rapidly effected than that which results from the setting in motion of the wheels by the action of the upper carbon-holder's

weight, the carbons are soon sufficiently apart to produce a voltaic arc of suitable size, which increases in length in consequence of the consumption of the carbons; but when their distance apart becomes too great, the intensity of the current becoming too weak is unable to cause the attraction necessary for the action on the wheel I, and then the wheels can turn freely, causing thereby the approach of the carbons, which goes on until the current has regained an intensity sufficient to again produce the effects we have already studied. By a suitable adjustment of the screws R, K, and Z, the double in-

verse action we have just examined may be made very regular. But this adjustment is very delicate, and that is perhaps an inconvenience of the system.

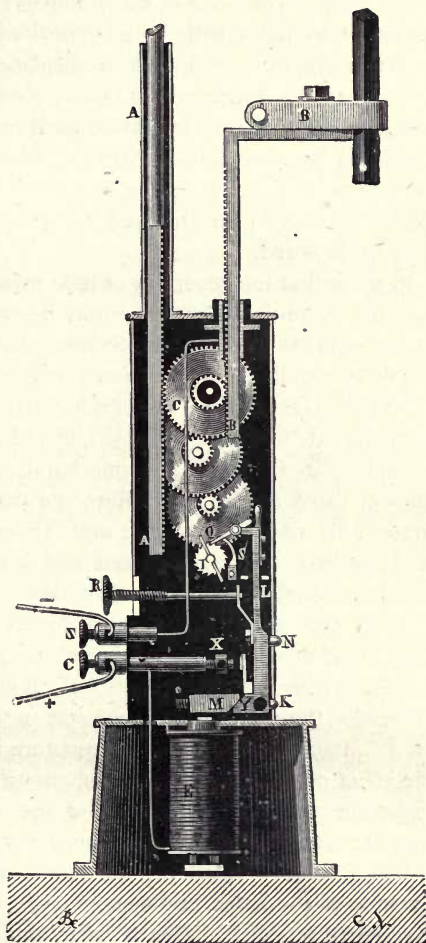


FIG. 41.

The apparatus is moreover provided with two other systems of regulating screws, one of which moves the two carbons and the luminous point without extinguishing it, and the other allows one of the carbons to be displaced. Finally, screws attached to the upper carbon-holder give a means of easily fixing the carbons with regard to each other so as to supply a diffused or a condensed light. Two small bull's-eyes in the side of the lamp allow the action of the delicate parts of the mechanism to be observed, and the effects of the regulator to be noted.

In order that the generator of light may work always under the same conditions, whatever may be the variations in the circuit external to the lamp, Siemens has interposed in the circuit a regulator of resistance which we are going to describe, as it has more importance than at first sight would be supposed; for these variations, by changing the conditions of velocity in the motor, on one hand, and on the other by causing many sparks, may injure the machine and the collector. By 1856 Lacassagne and Thiers saw the necessity of a regulator of this kind, and had invented one which I have described in my *Exposé des applications de l'électricité*, t. V., p. 506, and which was an accessory of their electric lamp; but these systems had been little used before Siemens.

Siemens' arrangement consists of an electro-magnet with a thick wire, the armature of which acts in the manner of a relay on a contact which, when the armature is not attracted, has the effect of introducing into the circuit a derivation with a resistance nearly equal to that of the voltaic arc. With a suitable regulation of the antagonistic spring, the derivation is therefore substituted for the voltaic arc whenever the resistance of the latter becomes so great that the armature is no longer retained. This is what happens not only when the lamp is put out or withdrawn from the circuit, but also when very great variations occur in the working of the lamp. The helix forming the derivation is placed in a tin vessel filled with water to prevent the wire from becoming too hot

during long interruptions of the current, such as those required by replacing the carbons.

The lamp just described is not, however, the only one made by Siemens. He has already patented eight forms.

Lontin's Lamp.—From a published account of the Lontin machines we extract the following description of this lamp:—

“The first and principal advantage of this regulator is that its moving and regulating parts are such that it can work in any position, upright, horizontal, or upside-down, and without being stopped or changed in its action by even the strongest shocks or oscillations.

“In these regulators a quite new application has been made of the heating produced by the current in a metallic wire to cause the separation of the carbons and keep it perfectly constant. Thus the use of electro-magnets is dispensed with, and the consequent cost of the additional electric power required to overcome their resistance in the circuit, while the length of the arc remains absolutely fixed, so that a more regular light may be obtained.

“The approach of the carbons in proportion to the combustion is obtained by another not less happy application of a derived current taken from the light current itself, and acting as follows:—

“There is a solenoid in the apparatus formed of a coil of fine wire in quantity sufficient to offer a very great resistance to the current. This coil encloses a movable iron rod, which when at rest keeps back the moving power that brings the carbons nearer together. So long as the carbons are at a distance adjusted to the amount required for a good light, the whole current passes through them, on account of the great resistance of the coil; but when the separation increases, a small portion of the current passes through the coil and excites it so that the movable iron rod is attractive, and the moving power released from its stop brings the carbons nearer by the amount required for maintaining the length of the arc; at this moment the solenoid ceases to act, and the iron rod again stops the motor, which has merely to bring the carbons nearer together and is extremely simple.”

This employment of a derivation from the light current

may also be advantageously applied to all the regulators which automatically separate the carbons, and it renders their action more certain and regular, whatever may be the variations in the intensity of the current. This system has been successfully applied to the Serrin regulators, used at the *Chemin de fer de l'Ouest* (St. Lazare station).

De Mersanne's Lamp.—De Mersanne's regulator was invented to enable straight carbons to supply an electric light for at least sixteen hours consecutively.

The system, represented in Fig. 42, is essentially formed of two slide boxes B B', fixed on a strong upright stand of cast iron. Through these slide the two cylindrical carbons c and c', each 75 centimetres or more in length, moved by a regulated action. In order that the carbons may be adjusted to have their points in the same vertical line, the boxes are capable of turning a little vertically, and the upper one can also be turned horizontally. The sliding system of both boxes consists of four grooved rollers, two of which are connected with the two ends of a lever, and are pressed against the carbons by a spiral spring *v*. These rollers serve as guides, and the other two, of larger diameter and with a roughened surface, act as the movers of the carbons. For this purpose these are set in motion by wheels fixed on an axle, connected by mitre wheels with a vertical shaft A A. This shaft, being capable of turning in either direction, according to the action of the regulating apparatus, can make the carbons approach to, or recede from, each other. The carbons are supported and protected outside of the boxes by enclosing tubes.

The regulating apparatus is placed in a case below the slide box B' of the lower carbon. It consists in the first place of clockwork driven by a spring barrel,* and by an electro-magnet E forming part of a derived circuit from the

* This barrel, when wound up, will act for 36 hours without attention.

two carbons, as in Lontin's system ; and in the second place, of another electro-magnet *M* interposed in the same derivation, and acting on the box *B'* of the lower carbon in such a manner as to separate the carbons when they come into contact. When the apparatus is not in action, the carbons are generally separated by a greater or less interval; but as soon as the circuit is closed through the apparatus, the two electro-magnets are excited, for the current then wholly passes through the derivation, and the clockwork is liberated, while the lower holder is so inclined as exactly to bring the two carbons one over the other. The advance of the carbons takes place slowly, and when they come into contact, the current, finding a more direct path, abandons the derivation and the electro-magnets, and passes almost entirely through the circuit of the carbons, which then glow, and immediately supply the voltaic arc. The electro-magnet *M* having become inactive, the box *B'* of the lower carbon-holder is slightly inclined forward, and by this causes not only the disjunction of the carbons, but also a sufficient separation of their points in consequence of the action produced on the

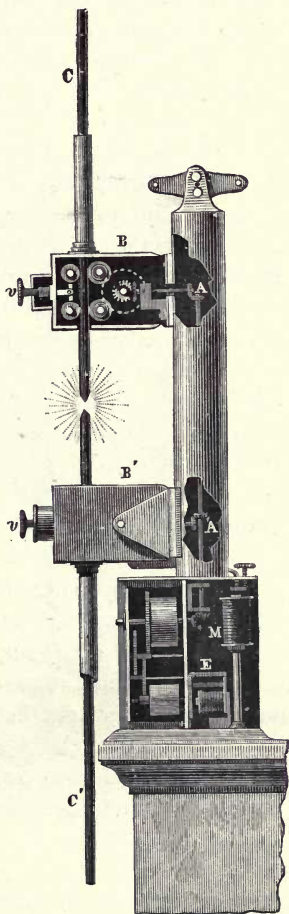


FIG. 42.

wheels by the movement of the box. The lamp is thus lighted; but in proportion to the consumption of the carbons, the resistance of the light circuit increases, and the current, passing with more intensity into the derivation, soon becomes sufficiently powerful to release the clockwork that brings the carbons together, until the current has regained its full intensity in the light circuit. Things go on in this way until the carbons are entirely consumed.

It will easily be understood that with this arrangement there is no limit to the length of the carbons, since it may exceed that of the apparatus, and without their requiring any particular position. Their forward movement takes place as if they glided between the fingers of two hands, pushed towards each other by two thumbs guiding their progress.

This lamp, like those of Serrin and Siemens, may be lighted from a distance, which is not one of the least of its advantages. A medal was awarded to it at the *Exposition Universelle* of 1878.

Bürgin's Lamp.—This lamp is already rather old, and we are surprised that it has not been described anywhere, for, according to what Soret has communicated to me, it works in the most satisfactory manner. It was shown at the *Exposition* of 1878, but, its inventor being absent when the jury went round, it was not examined. It is used continuously at Geneva for the theatre and for the illumination of a public clock.

Bürgin has made two patterns of this lamp, one of which is for industrial purposes, and is represented in Fig. 43; the other, more complicated, is intended for scientific experiments. The principle of the lamp is very simple: the two carbon-holders tend to approach each other continuously by the influence of a spring barrel or a counterpoise; but they can obey this tendency only when a check controlled by an electro-magnetic action permits the passage of the chain or chains which support the carbon-holders, so that, according

as the current is more or less energetic, there is motion or rest in these carbon-holders. In the pattern shown in Fig. 43, this result is obtained by means of a large wheel R, which carries on its axle the pulley C, on which is wound the chain supporting the lower carbon-holder.

The axle of the wheel rests on a piece of iron A A fixed to a jointed parallelogram, and serving as the armature of an electro-magnet E connected with the light circuit. A spring break F presses on the circumference of this wheel, and is sufficiently bent to prevent the wheel from turning when the latter is at the proper height, that is to say, when the armature A is at its greatest approximation to the electro-magnet E;

but when, in consequence of the weakening of the current, this armature is at a greater distance, the wheel, by dropping with the armature, withdraws from the break and is then able to turn by the effect of the weight of the lower carbon (or of a spring barrel attached to this carbon-holder), acting through the chain which is wound about the pulley C. Thereupon the lower carbon-holder rises, and the current, resuming its

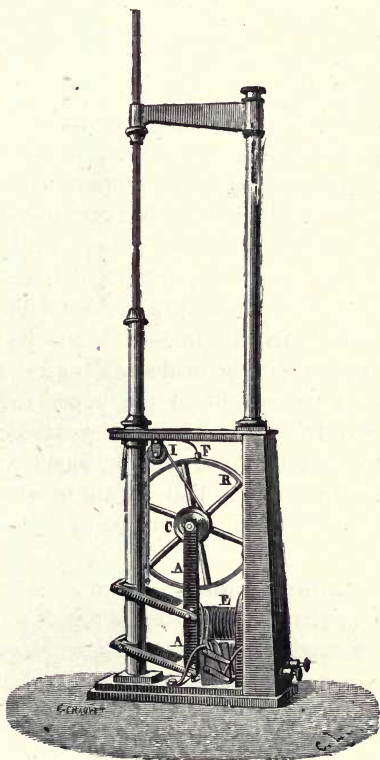


FIG. 43.

energy, quickly produces a fresh engagement of the wheel, which checks the rise of the carbon at the proper instant. The slight movement of the attracted armature A, when the carbons are in contact, suffices to allow the passage of enough chain to bring about the separation of the carbons when the circuit is closed.

In this pattern the upper carbon is fixed, and therefore the luminous point changes its position, a thing of no consequence for ordinary illumination; but for experiments of projection, the two carbons must be so arranged as to move simultaneously in the proportion of 2 to 1, and for this purpose Bûrgin fixes the two carbon-holders to two chains, which are wound upon two pulleys of unequal diameter, mounted on the axis of the large regulating wheel, so that each movement of that wheel causes a double displacement of the carbons. An adjusting screw attached to the break allows the apparatus to be made more or less sensitive. In this pattern it is the weight of the upper carbon-holder which, as in Serrin's regulator, brings the carbons together, and the attractive action of the electro-magnet first determines their separation in order that an arc may be formed, and afterwards stops them so as to maintain their due interpolar distance.

Gaiffe's Lamp.—In 1850, Archereau, reflecting upon the considerable space that a rod of soft iron will move within a coil under the influence of the magnetic attractions, invented a regulator based upon that principle. He formed one of the carbon-holders of a rod, half of copper and half of iron, placed within a long coil, and to properly balance the attractive force he used a counterpoise. This was, therefore, one of the simplest of regulators, and it had the advantage of being capable of lighting at a distance. In the hands of skilful experimenters, it could work well, but the movements being too abrupt and the oscillation too large, it often went out, and was not in fact a practical lamp. Jaspar and Loiseau succeeded in lessening these defects, but it was not

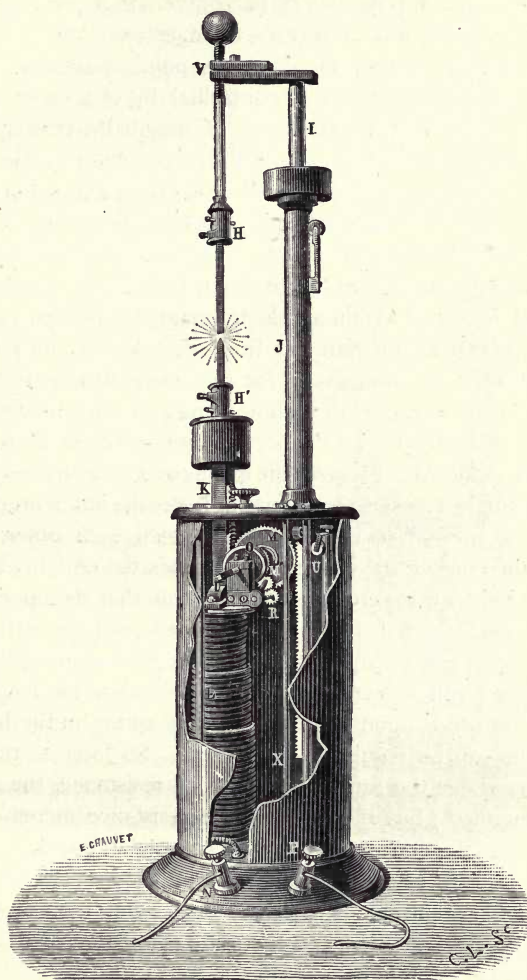


FIG. 44.

until Gaiffe invented the regulators represented in Fig. 44 that the advantage of this plan became obvious.

In Gaiffe's Lamp the two carbon-holders H, H' are movable, as in Foucault's and in Serrin's arrangements, and they are so arranged as to keep the luminous point stationary. For this purpose their motion is controlled by two racks K, U , which engage two wheels M', O , of unequal diameter, and moved by a simple spring barrel on the axle of which they are fixed. This barrel is wound up by the mere separation of the carbon-holders, which are, however, perfectly balanced and turn between sets of rollers. The lower carbon-holder is terminated by an iron rod K , to which is attached a rack, and this rod is placed within an electro-magnetic bobbin L , with a coil increasing in diameter from its upper to its middle part in order to compensate for the unequal action of the spring barrel through the whole range of this movement. Finally, a small wheel R connected by the wheels M', O , and another to the wheel M gives the means of simultaneously acting on the two racks so as to raise or lower the luminous point.

In the normal state the carbons touch each other, and when the current traversing them excites the coil, the lower carbon-holder is lowered at the same time that the upper one HVI is raised, and this effect is continued until the attractive force of the coil balances the resistance of the spring barrel, and thus a voltaic arc is produced. Of course the length of the arc depends upon the tension of the spring in the barrel, and this can be regulated by a screw. So long as the arc remains under the same conditions of resistance, the effect is maintained; but the moment the resistance increases on account of the consumption of the carbons, the power of the spring prevails over the electro-magnetic action, and the carbons are brought nearer together, until a condition of equilibrium is again attained, and the same thing goes on until the carbons are entirely consumed.

The small mechanism fitted to the wheels of the racks allows the luminous point to be raised or lowered, by means of a key, without the lamp going out, and this is necessary in optical experiments in order to properly centre the light.

Carre's Lamp.—Carre's Lamp, which received a gold medal at the *Exposition* of 1878, and is represented in Fig. 45, is only an ingenious improvement on Archembau's and GaiFFE's regulators. As in those, the electro-magnetic action is founded on the attractive effects of solenoids, but these effects are by an ingenious arrangement very much magnified, and the mechanical action is produced, as in the regulators of Serrin, Foucault, &c., by clockwork acting on two racks D, E, fixed to the carbon-holders, and controlled by a detent brought in action by the electro-magnetic system.

This system is formed of two coils B, B', having their axes slightly curved, and into these pass the ends of a soft iron core A A bent into an S shape, and turning at its middle part about the centre c. A double set of antagonistic springs r, r' , regulated by a system depending upon the adjusting screw v, allows the force opposing the attraction of the coils to be suitably adjusted, and

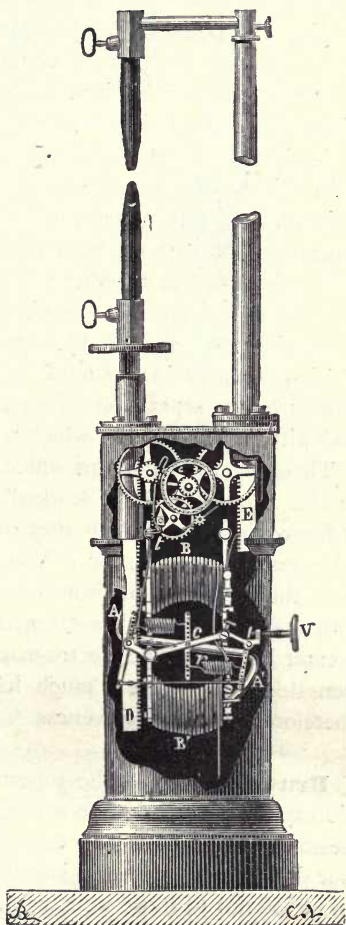


FIG. 45.

a rod *t* fixed to the magnetic core acts on the detent of the clockwork. The motion of the wheels causes a forward movement of the two racks in the proper proportion for keeping the point of light stationary. The light current passes through the two coils, and according as its intensity is greater or less, the iron core is more or less attracted within the coils, a sufficient enfeeblement causing a release of the detent, whereupon the approach of the carbons ensues.

In this system, as in those of Archereau, Gaiffe, Jaspar, Loiseau, &c., the increase of the current has the effect of separating the carbons from each other, and the clockwork brings them nearer together; but as under these conditions the path of the movable piece in the electro-magnetic system is considerable, and as the attractive effect is much less sudden than in the case of electro-magnets with turning armatures, the separations of the carbons are produced freely and without oscillations, which is an advantage.*

These are the regulators which, during the whole duration of the *Exposition*, have worked with the machines of the *Alliance Company*. With alternately reversed currents, they offer real advantages, for J. Van Malderen has shown that with these currents an iron rod is almost as strongly drawn into a coil as with direct currents, only there is a much greater heating of the electro-magnetic system; but to compensate for this there is much less residual magnetism, and therefore greater sensitiveness.

Brush's Lamp.—The report of the American Commission appointed to examine magneto-electric machines having bestowed great praise on this lamp, we have considered it our duty to give a description of it here, although it appears to us inferior to those we have in France.

This lamp, which is represented in Fig. 46, is, like the preceding, based on the attraction of solenoids. The electro-

* See the laws of the attractions of solenoids in *tome II.* of my *Exposé des applications de l'électricité*, p. 132.

magnetic coil is at *A*, above the upper carbon-holder, and is supported by the arm *b* fixed to a vertical piece *c* sliding within a column so as to adapt the apparatus to different lengths of carbons. Inside of the coil a magnetic core *d* moves freely. This core is hollow, and through it passes the copper rod *ff* of the upper carbon-holder, sliding freely for its whole length. A sort of collar *h* grasps it, however, a little below the magnetic core, and is so arranged that when it presses on a cross piece *h*, forming part of the fixed system of the arm *b*, it leaves the rod *ff* free, which then descends by its own weight. The collar therefore maintains the rod only when it is itself raised up, and this takes place almost constantly during the working of the apparatus, for a catch *e* fixed on the magnetic core supports it above; but in its rise it cannot go beyond a certain limit which can be adjusted, for a screw *x* has a head large enough to hold it by its upper edge.

The magnetic core itself is kept up by a cross piece on which act two spiral springs, the rods of which serve at the same time as guides. The carbon-holders have no particular feature; one is fixed to rod *ff*, the other to an

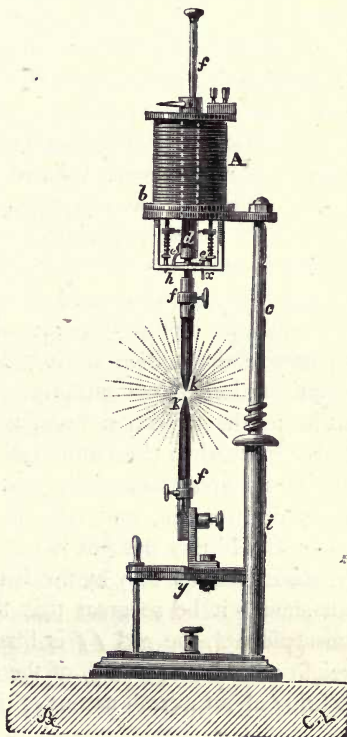


FIG. 46.

arm fitted to the supporting column, and this last is arranged in such a manner as to be capable of moving when the consumption of the carbon requires; for in this system it is only the course of the upper carbon that is regulated electromagnetically, as in Archereau's original regulator. We must add that the coil *A* is formed of two helices which may, by means of a commutator shown at the top of the coil, be arranged either for tension or for quantity, according to the conditions of the experiment.

The action of this apparatus will be readily understood: when it is not working, the two carbons *k k* are in contact, and the current can pass through them when the carbon-holders are connected with the electric generator. Under the influence of the current, then at its maximum intensity, the magnetic core *d* is raised up, carrying with it, by its catch, the collar *h*; the rod *ff* is then raised, and the two carbons separated; the voltaic arc is produced, and, so long as the electric action is kept within proper limits, the apparatus remains in the condition brought about by the rise of the core *d*; but when the consumption of the carbons becomes sufficiently great to notably weaken the current, the core *d* drops down again, and with it the iron rod *ff* and the collar *h*. If this descent is not complete, the carbons approach each other only by the distance the core has dropped; but should it be so great that the collar *h* presses on the cross piece *h*, the rod *ff* is liberated and falls by its own weight until the approach of the carbons is sufficiently great to bring about a fresh ascent of the core *h*.

Jaspar's Lamp.—Jaspar, of Liége, was one of the first to turn his attention to electric lamps, and in the second edition of our *Exposé des applications de l'électricité*, published in 1856, we have described the first system he sent to the *Exposition* of 1855. Since that time he has paid little attention to the subject, and it was not until the *Exposition* of 1878 that he again entered the lists with other inventors of

lamps and obtained a gold medal. This honour compels us to give some details of this new apparatus, which, it appears, acts remarkably well.

The apparatus is, like the preceding, based upon the attraction of solenoids acting directly on the carbon-holders by means of chains passing over pulleys of unequal diameter, and this action can be regulated by a counterpoise which acts on the antagonistic force. But the improvement in the original apparatus consists in this: the lower carbon acts on a rod with a piston which moves freely in a tube filled with mercury, and produces two useful effects. In the first place, it prevents any abrupt movement of the carbon-holders, for the mercury being able to pass but slowly through the narrow space between the piston and the interior surface of the tube, resists a too rapid rise or descent; in the second place, it affords an excellent contact for the negative rod.

The small counterpoise serving as antagonistic force has also a happy arrangement. It slides on a small rod jointed horizontally, with one end connected with the free extremity of the chain of the lower carbon-holder; so that, by moving backward or forward an externally projecting stud, its effect may be increased or diminished.

Experiments made with this lamp have proved very satisfactory. It is now applied at Sautter and Lemonnier's, in the workshops of Cockerill and Seraing, in Denayer's paper manufactory at Willebroek, at the *Gare du Midi* at Brussels, &c.

Rapieff's Lamp.—This system is only an extension of Bailhache's, in which the carbons are kept always at the same relative distance in spite of their consumption, by means of a spring pressing on them like the candle springs of carriage lamps. In Bailhache's system the carbons were kept at a distance suitable for the formation of the arc, by two hollow cones of calcined magnesia in which their points were placed, and which formed a kind of stop-collar. As

their extremities burned away, they were pushed forward by the springs, and as they became thin by burning at the extremities only, the cold part always remained within the refractory cone. In Rapieff's system the same effect is produced, but there are no refractory cones, these being replaced by four sticks of carbon joined at the ends two by two at an acute angle, and so arranged one above the other as to form two angular systems in planes perpendicular to each other. The points of contact which form the electrodes are separated one from the other by the distance desired for forming the voltaic arc. Counterpoises with pulleys are arranged to push the carbons of each system one against the other, and then, as these carbons are consumed, they constantly advance towards the common point of intersection, which remains always at the same place.

Fig. 47 represents this regulating system, the carbons of which, $a a'$, $b b'$, seem to form an X, with this difference, that the two lower carbons are placed in a plane perpendicular to that in which the upper ones are placed. The voltaic arc is produced at c , between the upper and the lower pairs of points. As the carbons are consumed, they slowly move nearer to each other in each couple, under the influence of a counterpoise w , which, through the cords and the pulleys $W f h d a' a e g d' b' b$, pushes the sticks of carbon against each other. This counterpoise is guided in its course by two columns $s s'$, which at the same time serve as conductors for transmitting the current to the two systems of electrodes $a a'$, $b b'$, supported also by the two metallic arms $d h$, $d' g$. As the upper carbons are to be connected with the positive pole, they are of course longer than the lower. This arrangement is completed by an electro-magnetic system enclosed in the base of the apparatus; and its office is, when the current passes and the four sticks of carbon are in contact, to separate the two systems to the distance necessary for the formation of the arc. This effect is produced by means of a cord attached to the electro-magnetic armature, which cord,

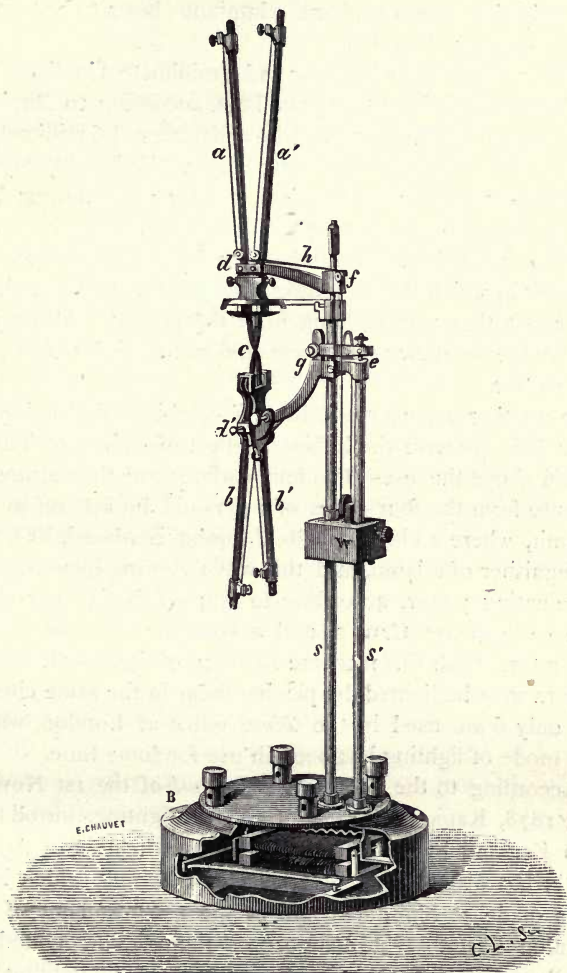


FIG. 47.

passing within the column *s*, acts on the arm *d'* *g*. A reflector of a cup shape, either of silvered copper or of porcelain, is fixed a little above the point of contact of the carbons,

and adjusting screws enable the luminous beam to be turned in any required direction.

With carbons 20 inches long and 5 millimetres in diameter, the light supplied by the lamp lasts, according to Rapieff, for seven or eight hours ; but with a diameter of 6 millimetres these carbons may last two hours longer. This light may be reckoned at 100 or 120 gas-jets, or at 1,000 candles ; but with Rapieff's smaller patterns one may be obtained not exceeding 5 gas-jets. The inventor has also constructed patterns in which the preceding arrangement is reversed, in order that they may be hung from the ceiling. According to him, the resistance of the arc does not exceed 3 ohms, or 300 metres.

In another arrangement Rapieff combines the action of the voltaic arc with the luminous effect of a piece of kaolin placed above the arc. The four carbons are then arranged so as to form the four edges of a pyramid broken off at its summit, where a kind of bell of kaolin is placed, like the extinguisher of a lamp, and this when glowing increases the illuminating power, according to Rapieff, by 40 per cent. The carbons are Carré's, and a Gramme machine is the generator. With this machine 10 lamps of the first described pattern may be lighted by placing them in the same circuit, but only 6 are used in the *Times* office at London, where this mode of lighting has been in use for some time.

According to the *Telegraphic Journal* of the 1st November, 1878, Rapieff's system of electric lighting, introduced into England by E. J. Reed, under the direction of Applegarth, has given excellent results in the trials which have been made at Smithfield and at the establishment of the London *Times*. The compositors' room is now lighted by 18 Rapieff lamps, and 6 are appropriated to lighting the offices. "The great advantage of this lamp," he says, "is that it will go a whole night without a renewal of the carbons ; its intensity is always constant, even when the carbons are burned very low, and in this respect the lamp is prefer-

able to the Jablochkoff candle, for in this the current increases in energy as the candle burns on account of the decrease in the length of carbon the current has to traverse, whilst in the Rapieff lamp that length is always the same.

In order that the extinction of one lamp may not cause that of other lamps, Rapieff arranges the electro-magnet that separates the carbons in such a manner that it acts as a commutator. When the current passes through the electro-magnet, the commutator is not brought into action, and the circuit is completed through the lamp; but when this is extinguished or withdrawn from the circuit, the electro-magnet in question becoming inactive causes the current to pass through a derivation on which a resistance equal to that of the lamp circuit is introduced, and the circuit of the other lamps is not interrupted thereby. This effect is obtained by means of a second armature, which, being attracted when the current passes, acts as a keeper, thus increasing the electro-magnetic action exercised on the lamp, and sets the commutator in action, when the current no longer passing, the armature yields to the antagonistic action.

In a new pattern, Rapieff has replaced the upper carbons of the regulator we have described by a large piece of carbon, which, as in Werdermann's lamp, does not burn. This arrangement had, however, been indicated by Rapieff in his patent of 1877, so that he cannot be accused of having imitated Werdermann in his new arrangement. It is this form that is now most employed.

Baro's Lamp.—This apparatus is composed simply of two metallic tubes placed vertically one beside the other, and in these slide freely two sticks of carbon, which rest on a block of magnesia. These tubes are separated by an insulating substance, but a screw regulates the distance between the carbons at the end in contact with the magnesia, so that the arc may be produced at this point of contact under the desired conditions, and be kept there in spite of the con-

sumption of the carbons, for these continually tend to approach the block of magnesia by their own weight. A lamp of this kind had previously been invented by Staite.

27 **Wallace Farmer's Lamp.**—This system is so primitive that we are surprised that it has received any attention. It was invented with a view to obtaining a longer duration of the carbons, and with this object thin plates of carbon are used instead of carbon pencils. These plates are placed so as to form a very small angle with each other, so that the arc may be progressively displaced as the carbons are hollowed out. An electro-magnetic mechanism analogous to those of the other lamps brings the plates nearer together as the action proceeds, and this mechanism acts by variations in the intensity of the current. It is certain that a lamp on this system will remain lighted for a long time ; but we very much doubt whether the electric intensity it produces can be compared with that of other lamps, for the incandescent part of the carbons is then considerably reduced in extent and calorific intensity.

24 **Houston and Thomson's Lamp.**—As regards arrangement, Houston and Thomson's Lamp resembles the ordinary apparatus ; only the lower carbon, instead of being connected with a clockwork mechanism, is supported by an arm fixed to a strong flat spring. This arm carries the armature of an electro-magnet placed below it, and is insulated metallically from the upper carbon-holder, which is placed in communication with the positive pole of the electric generator. The electro-magnet is in metallic communication with the lower carbon and the negative pole of the generator, so that the circuit is completed through the elastic arm of the lower carbon-holder and the two carbons. The electro-magnetic armature forms therefore a trembler, as in an electric bell, and the effect is a very rapid series of interruptions of the current between the two carbons ; and this occasions repeated sparks,

and thence a continuous light by their superposition on the organ of sight. In order to avoid a continuance of the action on the carbon-holders when the carbons are consumed, the upper carbon-holder has a head, which by meeting a circuit-breaker stops the current through the apparatus. Under these conditions, the spark of the extra current of the electromagnetic system is joined to that of the generator, and increases its brilliancy.

Houston and Thomson do not, of course, announce this regulator as suitable for feeble currents and lights. Maiche sought the same object, and Lemolt also used this means to produce a voltaic arc with powerful generators, only it was a clockwork mechanism which gave the vibrating movements to the carbons.

Molera and Cebrian's Lamp.—This system of lamp was invented for distributing the light in several directions by optical means. The apparatus consists, therefore, of a regulator, with the luminous point enclosed in a polyhedric cage, with faces provided with Fresnel's lenses. With this object, the two carbons are supported by two systems of regulating carbon-holders entering at a certain angle within the cage, and directed towards its centre. These carbon-holders are fitted to the two ends of a tube filled with a liquid, in which they form a kind of pistons which may be pushed to a greater or less distance according to the pressure exercised by the liquid in the tube. At one part of this tube there is a kind of bellows, the movable part of which is provided with a plate of iron, which serves as the armature of an electro-magnet placed in the arc circuit. This armature being more or less energetically attracted, according to the greater or less intensity of the light current, exercises a greater or less pressure which causes the carbons to advance proportionally to their consumption, and therefore maintains them in the centre of the cage. This pressure may, however, be regulated by means of an antagonistic screw. When

the current is interrupted or weakened, the spring acts so as to bring the carbons nearer together; when, on the contrary, it increases, the inverse effect is produced and the carbons are separated. Lacassagne and Thiers had, as will be presently seen, used a system of the same kind.

On each face of the polyhedron, formed by the reflexion cage, abut tubes which are arranged so as to carry the rays projected by the lenses in certain directions; and according to the *Scientific American*, these tubes may be placed in the streets, along buildings, or even under the floors, in order to distribute the light in a house. For that purpose it would suffice to fix a stout branch pipe with a properly inclined mirror at each change of direction.

By means of this system, says the American journal, each street in a town may be provided with one or more pipes carrying a certain quantity of light, which may always be governed by simply changing the position of the reflectors. The problem may thus be reduced to the conditions of a water supply.

Without stopping to discuss these rather fantastic dreams of American inventors, we think we ought to give here some figures they have published relative to the system of lamp we have described. According to these, 195 lamps on this system can be supplied by 1-horse power, and a light obtained equivalent to 1,958 candles, for which it follows that this illumination would cost only one-twentieth the price of gas. It is needless to say that we cannot accept such figures, and if we give them, it is only to show to what length the prolific imaginations of Americans will go. (See the *Telegraphic Journal* of 15th July, 1879, p. 231.)

Lamps of various kinds.—In order to complete our monograph of the voltaic arc lamp, it remains only to speak of various plans which, although they have not given very important results in practice, nevertheless have an originality of character which deserves attention. Of this number is

Girouard's lamp, which is a clockwork regulator somewhat resembling that of Foucault or Serrin, but acting under the power of a kind of relay-regulator, and therefore capable of being controlled from a distance. The system consists, therefore, of two apparatus: 1°. An electro-magnetic coil with thick wire, through which the current of the generator passes, and which acts on a double contact; 2°. A lamp with a double clockwork motion, on which act two electro-magnets with fine wires, excited by the current of a battery of very feeble intensity. The current of the generator, after having traversed the electro-magnet of the relay-regulator, passes directly, therefore, through the carbons of the lamp, and their distance apart is regulated by an independent system which works by the influence of the two contacts of the relay-regulator. When the current has its full intensity, the mechanism controlling the separation of the carbons is set in motion, and when on the contrary the current is too much enfeebled, the second clockwork mechanism is liberated, and this brings the carbons nearer together. In order to obtain this double action in opposite directions, Girouard used a spring barrel with a double movement. The complete description of this system may be found in vol. V. of my *Exposé des applications de l'électricité*, p. 495.

In order to increase the duration of the carbons, circular carbons have been used. Indeed, the first electric lamp was made by Thomas Wright on this system. Subsequently, in 1849, Lemolt, taking up Wright's idea, constructed a better apparatus, in which the two discs of carbon, supported by two curved and jointed levers, were set in motion by a double system of pulleys driven by the clockwork mechanism. A spiral spring connecting the two curved levers, pressed the two carbon discs against each other, and these were separated at very short intervals by the action of an eccentric put in motion by clockwork. The result was a series of sparks succeeding each other rapidly enough to impress the sight as a continuous light. After this system came that of

Harrison, in which one of the carbons was replaced by a carbon cylinder, movable on its axis, so as to make the consumption slower. The upper carbon was moved by an electro-magnetic system, which determined the formation of

the arc and kept it constant by means analogous to those employed in other regulators.

Ducretet has improved this lamp by arranging it so as to give simultaneously with the arc powerful incandescent effects. Fig. 48 represents this new arrangement, which, I am told, has given very good results.

Lastly came Reynier's system, the most complete of all, in which each of the carbon discs was set in motion separately by a special clock-work mechanism, and the separation necessary for the production of the arc was obtained by an

electro-magnetic system acting on one of the carbon-holders, and producing effects like those in the other regulators of this kind. (See my *Exposé*, t. V., p. 502.)

Besides the apparatus of which we have just spoken, there exists a class of electric lamps to which, in my work on the applications of electricity, I have given the name of regulators with hydrostatic actions, and which are at least very interesting, though not very practical. For the regulating

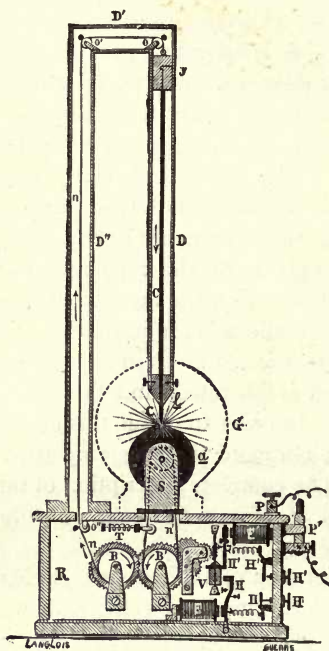


FIG. 48.

organs, they have liquids which act either by communicating vessels, or by serving as the medium of discharge under certain conditions, or by producing an effect like that of the moderator lamps. The principal forms in this class are those of Lacassagne and Thiers, Pascal of Lyons, Marçais and Duboscq, and Way.

In Lacassagne and Thiers' apparatus, invented in 1856, only the lower carbon is movable, and it is directed by a float fitted in a long cylinder filled with mercury, which is placed in communication, by a tube, with a reservoir of the same liquid, and this last is fixed on the column that supports the upper carbon-holder. The tube that establishes the communication between the two vessels is bent across one of the poles of a powerful electro-magnet so as to present its curvature beneath the armature, and from this arrangement it results that the armature, pressing on the part of the tube when the current has its whole intensity, plays the part of a stopper. So long, therefore, as the current keeps all its power, the level remains the same in the two vessels, and the lower carbon continues motionless; but when the current becomes feeble by the increase of the length of the arc, the tube is then liberated a little, and a small quantity of the liquid passes from the reservoir into the tube, and this causes the carbon to rise until the current, having resumed its original intensity, has again occasioned the obstruction of the tube. The action of the spring antagonistic to the electro-magnet is regulated by a second electro-magnet placed in a very resisting derivation of the circuit, and which acts in the same direction as it would on the armature of the large electro-magnet, which is for this purpose prolonged beyond its pivot.

Marçais and Duboscq's regulator is a kind of moderator lamp, the rack of which acts on the two carbon-holders by means of a double pinion, and in which the movement of the piston depends on the more or less rapid flow of the oil below it. For this purpose, the upper and lower parts of the

body of the lamp are connected by a tube, at one part of which is a circular opening stopped by an extensible membrane, and above this membrane a kind of plug is applied controlled by the armature of an electro-magnet, which, as in the foregoing system, stops or allows the flow of the liquid according to the greater or less intensity of the current.

In Way's lamp, which was much talked about in 1856, and which moreover caused its inventor's death, the carbons between which the voltaic arc is generally produced were replaced by a fine stream of mercury issuing from a small funnel and received into an iron basin also containing mercury. The two poles of the generator being connected, one with the funnel and the other with the basin, a series of voltaic arcs were produced between the successive drops of the discontinuous stream, and the combination of these arcs formed a source of light tolerably brilliant and uniform. The luminous vein was enclosed by a glass tube sufficiently narrow to become so hot that the mercury should not condense on its surface; and as the action took place out of contact with oxygen, the mercury was not oxidized. Way modified this first arrangement by using two jets of mercury instead of a single one, and these jets were so arranged that they met together at one point, from which they flowed on in drops. He also closed and interrupted the currents continually by means of a small electro-motor set in motion by the battery, and which drove the mercury pump that supplied the jets. But in spite of these improvements, it was necessary to abandon this apparatus on account of the mercurial vapours that escaped from it, and which at length killed the inventor. Moreover, the light attained to little more than a third of that produced by the same current between two carbon points.

As a special form of arc lamp, I must say a few words about J. Van Malderen's regulator, which is based upon the repulsions between the contiguous elements of one and the same current. It is a kind of suspended compass, the

jointed arms of which carry at their ends the carbon-holders, which are therefore horizontally opposite to each other. These two arms of the compass are insulated from each other and are very readily movable. They are connected with the two branches of the circuit, and when the carbons come into contact by the tendency of the carbon-holders to place themselves vertically, the passage of the current which then takes place produces a repulsion that separates the carbons and produces the arc. There is then established a state of equilibrium between this repulsive force and that due to gravity. This state of equilibrium is sufficiently stable to render the arc comparatively steady. But this system can be used only with currents of small intensity, and it cannot be considered of any practical use. The same may be said of that of Fernet, which is arranged according to the same principle.

In conclusion, we shall mention a lamp invented by Dubos, which is rather interesting from its arrangement.

In this lamp the luminous point remains fixed without any clockwork, in consequence of the shape of the two carbons, which are semicircular. These carbons are supported by two arms jointed to a pivot in the centre of the circumference formed by the two carbons. As in the ordinary regulators, an electro-magnetic mechanism fixed to the carbon-holders brings them together as they are consumed. As these displacements take place circularly, the point of contact of the two remains always at the same height, and consequently the same is the case with the luminous point.

There are yet a few other lamps which were shown at the Exhibition at the Albert Hall, and which have been described in various works, in those of Fontaine and Higs, among the rest; but these lamps are merely more or less complicated modifications of those we have described, and therefore we shall here merely make a note of them. Of these, we shall

mention the lamps of Régnard, Hiram Maxim, H. Fontaine, Marcus, Crompton, Hackley, Krupp or rather Dornfeld, Chertemps, &c. This last is little more than Archereau's regulator improved, but it has the advantage of being cheap

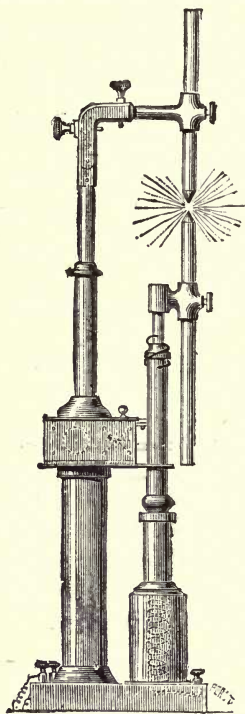


FIG. 49.

and of working in a tolerably steady manner. It was shown at the *Exposition* of 1878, and we give a representation of it in Fig. 49.

Dornfeld's system resembles Bürgin's, that of Hackley is like Van Malderen's. Crompton's lamp is only a Serrin regulator, in which the carbons may be placed above or below the case containing the mechanism, and thanks to this arrangement the lamp can simultaneously give two luminous points. Finally, H. Fontaine's and Hiram Maxim's lamps much resemble Serrin's lamp, but have their electro-magnetic systems a little different. These last two apparatus are represented and described in the new edition of Fontaine's book, as is also that of Marcus, which is very like Gaiffe's. Régnard's lamp is only a complication of

De Baillache's, and makes use of very slender carbons, and is therefore of little practical application.

INCANDESCENT LAMPS.

The interesting experiments undertaken by Lodyguine and Kosloff prompted several inventors to contrive lamps for obtaining the electric light by the incandescence of the carbons. It seems, however, according to Fontaine, that King, as early as 1845, had invented the first lamp of that kind.*

King's and Lodyguine's Lamps.—King's lamp consists of a slender rod of retort carbon fixed at its ends into two carbon cubes, and supported by a stand with two porcelain arms. The whole is enclosed in an exhausted tube, and the rigid conductors traversing this tube interpose the little carbon rod in the circuit of the electric generator, by which it is made to glow sufficiently to give a brilliant light. This is, it will be seen, a system somewhat resembling that of Lodyguine and Kosloff, mentioned on page 144.

This idea was taken up in 1846 by Greener and Staite, and in 1849 by Petrie. "Illumination by incandescence," says Fontaine, "and the principle of its production, had long been forgotten, when, in 1873, a Russian physicist, Lodyguine, resuscitated both, and made a small lamp, which was subsequently improved by Konn and Bouliguine.

In his lamp Lodyguine used carbons in one piece, diminishing the section at the luminous centre, and in the same apparatus he placed another carbon, through which, by means of a commutator, the current could be sent when the first carbon was consumed. Kosloff, who came to France expecting to work Lodyguine's patent, effected some little improvement in this lamp, without, however, getting at anything

* It is stated that this lamp was invented by J. W. Starr. (See the *Telegraphic Journal* of the 1st January, 1879, p. 7 and 15.)

passable. A relative of Truc, the Paris lampmaker, at whose house Kosloff's experiments were made, also worked at this lamp with much enthusiasm without effecting any material improvements; and it was not until Konn had invented his lamp in 1875 that it was possible to enter upon experiments which held out any promise of practical advantages from lamps of this kind. It was Duboscq who first made this lamp in France.

Konn's Lamp.—In this apparatus, which is represented in Fig. 50, each luminous centre, instead of having only one carbon, was provided with four or five, and all these carbons A B, arranged vertically and circularly, were terminated by small carbon cylinders in which were incorporated, in the upper parts, rods of copper A B of a successively decreasing length. Their lower part was connected with one of the branches of the circuit, but the upper part was connected with the other branch only by means of a kind of jointed metallic cap which rested on them by its own weight. Their height, however, being different, this cap could only touch the longer one. Now, it would follow from this arrangement that if this last were to break or be completely consumed, the cap would fall on to the next longer one, and would thus send the current through a fresh carbon, which would be instantly illuminated. The latter again breaking, the cap would transmit the current into a third carbon, and so on until the last. Experience had shown that five carbons thus arranged were ample for an evening's illumination, and during some experiments at which I was present I have twice seen the lamp working at the moment of the rupture taking place.

Each of these quintuple systems of carbons was of course enclosed in a hermetically sealed vessel w, from which the air had been exhausted, and their difference of height was calculated so that the curvature produced by the great heat should not cause a division of the current.

When all the carbons of one lamp were consumed, the cap, by meeting with a copper rod, continued the circuit ; so

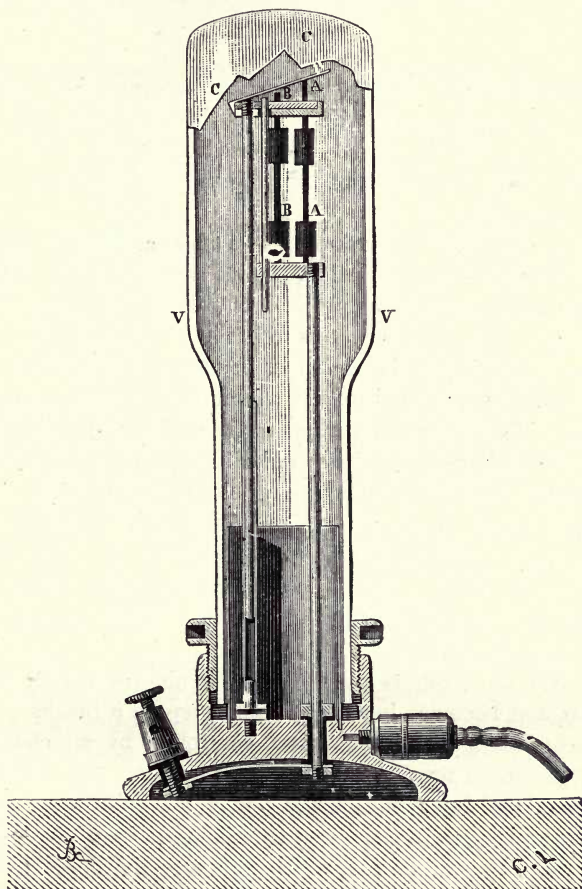


FIG. 50.

that, if there were several lamps included in the same circuit, the extinction of one of them did not involve that of the others :

According to the experiments made at Florent's, at St.

Petersburg, where three of these lamps are in operation, each of them gives a light equal to 20 Carcel lamps, and they are worked by the currents of one of the *Alliance* Company's machines.

Bouliguine's Lamp.—This lamp accomplishes nearly the same object as the preceding, but by using only one carbon. It is, like the former, composed of a copper base, two vertical rods, two bars for conveying the current, and a valve for exhausting.

One of the rods is perforated by a small opening from top to bottom, and nearly all its length there is a slit which allows two small lateral projections to pass through. The carbon is introduced into this rod as into a porte-crayon, and it tends to rise, by the action of counterpoises attached by very small cords, to the lateral projectors on which the carbon rests. The part of the carbon to be made incandescent is held between the lips of two conical blocks of retort carbon. A screw placed under the base enables the length of the rod which carries the upper conical block to be increased or diminished, and thus a greater or less length can be given to the luminous part. The closing of the globe is accomplished, as in the preceding apparatus, by the lateral pressure of several caoutchouc discs.

When the lamp is placed in a circuit, the carbon rod glows and becomes luminous, until at length it breaks. At this instant a little mechanism controlled by an electro-magnet opens the lips of the carbon-holders; the counterpoise of the upper one pushes out of the groove any fragments which may remain, and the counterpoise of the lower one raises the carbon rod, which goes into the upper block and re-establishes the current. The mechanism controlled by the electro-magnet again acts, but in the reverse direction of its former movement, the porte-crayons are tightened, and the light reappears.

This system, according to Fontaine, does not always yield

good results, on account of the multiplicity of its parts, but when by chance it does work regularly, the light it gives is more intense than that of the Konn lamp.

Sawyer-Man's Lamp.—This lamp is nothing more than King's or Lodyguine's in all its simplicity, except some insignificant arrangements for lessening the calorific radiation, and we are surprised at the long accounts we read in the English journals about this lamp, which is probably not better than the older ones. In this system, the vessel containing the incandescent carbon is filled with nitrogen to avoid combustion and the deposition of volatile products on the surface of the vessel. The carbon itself is rather short; its resistance does not exceed 0.95 ohm, and each light is supplied with a derivation, in order that the conditions of the distribution of the current may not be changed when any one of the lamps is extinguished. The commutator used for lighting and extinguishing the lamp is, moreover, arranged in such a manner that the current gains its full intensity only by degrees, and after having passed through successively weaker resistances. It is, according to Sawyer-Man, from neglect of this precaution that the carbons of incandescent lamps are so soon spoiled. Finally, an electro-magnetic register is included in the circuit, and has the same effect as a gas-meter.

We shall not speak of the system of distributing the current among all these lamps, for it is founded on the principle of derivation, and is identical with that of Werdermann, which we shall presently consider. A detailed description of this lamp may, however, be seen in the *Telegraphic Journal* of 1st January, 1879. We think it unnecessary to say more about it, than to express our surprise that English and American inventors trouble themselves so little about the earlier inventions.

E. Reynier's Lamp.—We have seen, on page 146, the principle on which this lamp is based. The lamp is the most

important of all those that we are now examining ; it perhaps may some day, under one form or other, solve the problem

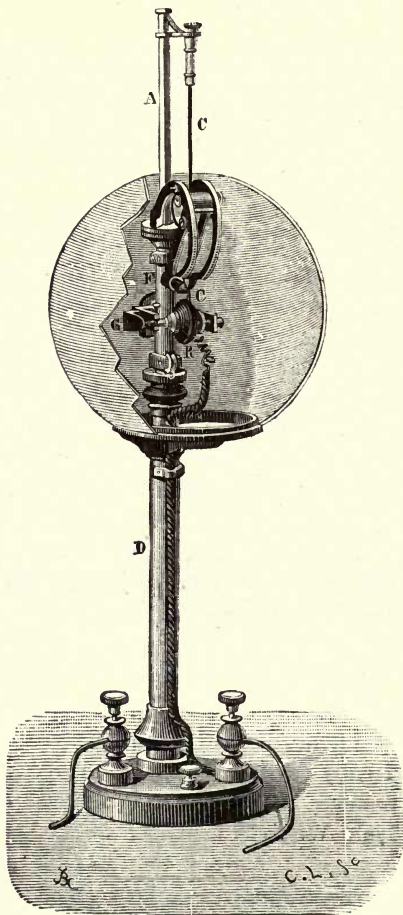


FIG. 51.

of the divisibility of the electric light. The best known form of it is represented in Fig. 51. It is composed, as will be

seen, of a long and slender rod of carbon c c 2 millimetres in diameter, supported on a heavy carbon-holder A , which slides on a hollow column D between four rollers. This rod rests on a cylinder of carbon R , turning on a horizontal arm C fixed to the column. A guide, fitted with a brake F , encloses the rod of carbon to a short distance (6 millimetres about) from the carbon cylinder, and at the same time conducts to it the positive current, which returns to the generator by the carbon cylinder and its support. A second brake F , placed behind the apparatus and resting on the support A of the movable carbon through an opening made in the tube D , moderates the action of the weight of the support A , according to the degree of pressure exerted on carbon disc R . For this purpose, the support of the axle of this disc forms a rocker, and on the side of the rocker opposite the disc R is fixed the second brake, of which we are speaking.

The point of contact of the rod of carbon with the cylinder is placed a little eccentrically, in relation to the vertical passing through the axis of the cylinder, so that at each lowering of the system from the consumption of the rod, a small tangential impulse may be given to the cylinder, which causes it to make a slight movement that suffices to throw down the ash accumulated at the point of contact. Without this precaution, this ash might interfere with the brilliancy of the light, at least with the impure carbons which are at present in use.

The problem which Reynier undertook to solve was, as may be seen, to make a long slender rod of carbon incandescent towards its extremity, and while wasting at the end, to be moved forward continuously and regularly. Fig. 52, taken from the French patent of the 19th February, 1878, clearly explains the data of this problem.

“A cylindrical or prismatic rod of carbon c ,” says Reynier,* “is traversed between i and j by a continuous or alternative

* See *le compte rendu des séances de la Société de Physique* for April—July, 1878, p 96.

current, intense enough to make this portion incandescent. The current enters or leaves through the contact *l*, and it leaves or enters through the contact *B*. The contact *l*, which is elastic, presses the rod laterally; the contact *B* touches it endways. Under these conditions, the carbon wastes at its extremity *j* quicker than at any other place, and tends to become shorter. Consequently, if the carbon *C* is continually pushed in the direction of the arrow so as to always press on the end contact *B*, it will advance gradually as it is consumed by sliding in the lateral contact *l*. The heat developed by the passage of the current in the rod is greatly increased by the combustion of the carbon.

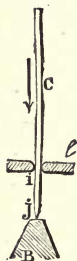


FIG. 52.

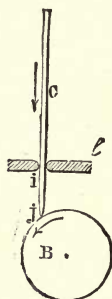


FIG. 53.

"In practice, I replace the fixed contact by an end contact *B*, Fig. 53, which removes the ashes of the carbon. The rotation of the end contact is concomitant with the progressive movement of the carbon rod, so that the position of the latter on the end contact acts as a brake on the moving mechanism.

"The principle of this new system of lamp having been established, it was easy to invent simpler arrangements for carrying it out. The samples which I have the honour of laying before the Society will explain themselves at a glance. The progression of the carbon *C* and the rotation of the end contact *B* are obtained by the descent of the heavy rod of the carbon-holder.* To wind up the lamp, this rod has merely to be lifted up. The rod of

* Comparative experiments made by Reynier prove that the renewal of the end contact is indispensable for obtaining a somewhat prolonged action with the ordinary carbons of commerce.

carbon is put in its place without any adjustment. There is no apparatus for regulating."

Previous to constructing the form of lamp we have described, Reynier had contrived a more complicated one,

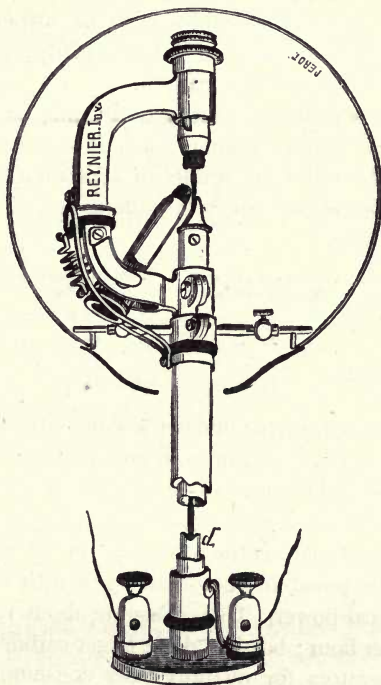


FIG. 54.

in which the carbon cylinder was moved by a clockwork mechanism, checked by the pressure of the carbon rod, the end of which formed a brake, so that the clockwork acted only as the carbon consumed. But he soon saw that the problem admitted of a simpler solution.

Quite recently Reynier has given his lamp the form shown in Fig. 54, which yields the best results. In this new pattern

the lateral contact has a less complicated arrangement, and the weight P which acts on the movable carbon to produce the end contact, is placed above the upper end of the carbon. It may therefore be selected as required. The end contact itself is fixed instead of turning round. The arrangement given to the apparatus enables it to be suspended from a ceiling. It can also be placed horizontally: in that case a spring propels the movable carbon.

Experiments made at Sautter and Lemonnier's, with ten Reynier lamps and a Gramme machine with a speed of 930 turns, gave the following results in a circuit represented by 100 metres of copper wire of 3 millimetres, or 30 metres of telegraph wire:

Number of lamps in tension.	Indications of the galvanometre.	Luminous intensity of each lamp.	Total yield of light.
5	25°	15 jets	75 jets.
6	22°	13 —	78 —
7	20°	10 —	70 —
10	15°	5 —	50 —

Serrin's regulator gave under the same circumstances, with a deviation of 21°, a luminous intensity of 320 jets.

As regards total luminous intensity, the use of incandescence lamps is therefore less advantageous than that of arc lamps; but with the former there is the advantage of the division of the light, and the possibility of obtaining it with comparatively small electrical power. They consume about 10 centimetres of carbon per hour; but by taking larger carbons and arranging the generators for quantity, this consumption may be much reduced. In the experiments made at the *Société d'encouragement*, six lamps could be lighted with the current from 25 double Bunsen cells. Their light through ground glass globes was soft, and appeared about equal to that of two or three gas-jets. They could be lighted and extinguished at will.

In the year 1876, S. A. Varley had patented a lamp on a similar plan which we show in Fig. 55, and which is described as follows:—

"A rod of carbon *T* rests gently by its weight and that of its carrier on the periphery of a roller of retort carbon *N*, and the *imperfect* contact thus produced gives rise to the incandescence and combustion of the stick of carbon at its extremity."

We may remark, however, that with this arrangement, in which the transmission of the current to the movable carbon is not produced by a sliding contact, placed at a short distance from the point, that the light is only produced at the point of contact, and it can be but very feeble, whilst with Reynier's system, in which this sliding contact exists, the portion of the carbon between it and the roller is heated to incandescence. It appears also, on an attentive examination of the patent, that the carbon roller *N* was made of alternately insulating and conducting portions; and as it was subjected to a rapid rotatory movement, the light was the result of a series of sparks which were produced at the moment of the passage of the carbon *T* on each of the insulating portions.

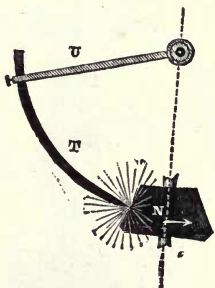


FIG. 55.

Werdermann's Lamp.—Werdermann's lamp is in principle merely Reynier's lamp reversed; but this arrangement is more practical for public illumination, for which it was specially intended, and it makes use of the voltaic arc action. It is represented in Fig. 56.

This system consists essentially of a slender carbon *b* moving within a metallic tube *T*, which serves at once as guide and conductor of the current. A collar fixed on the lower part connects it—by means of two cords which leave the tubes by two grooves and pass over two pulleys—to a counterpoise *P* that tends constantly to raise the carbon, and to keep it lightly pressed against a large carbon disc *c* of *z*

inches diameter, which is kept in a fixed position by a vertical support *D*. This support is fixed to a kind of funnel-shaped covering *S*, which receives the ashes from the combustion, and permits a glass globe to be fitted to the lamp.

The upper carbon disc is connected with the negative pole of the generator, and the metallic guide *T* of the carbon

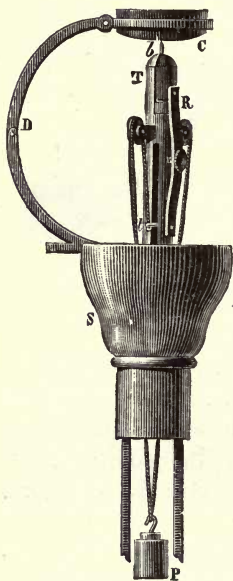


FIG. 56.

pencil corresponds with the positive pole, so that only the portion of the carbon between the tube and the upper carbon is brought to incandescence. This incandescence is increased by the action of the small voltaic arc which, as we have said, is formed at the point of contact of the two carbons, and it is increased also by the combustion of the attenuated carbon. The upper carbon, by virtue of its greater mass, neither burns nor changes. The action of the counterpoise is regulated by means of a spring *R* provided with an adjusting screw, which, by pressing more or less on the part of the tube surrounding the carbon, acts as a brake. The greater or less pressure of this brake depends on the formation of the voltaic arc between

the two carbons, or merely on the incandescent effects, and it is in this circumstance that the difference between Werdermann's and Reynier's system specially resides. In the latter the movable carbon is too contracted to take part in the formation of an arc, whilst in the other this carbon is sufficiently free for this effect to be produced; and thus the diameter of the movable carbon may without inconvenience be increased for the purpose of making it last longer. In the new forms of the Werdermann lamp the upper disc of

carbon has been advantageously replaced by a disc of copper.

Experiments made in England with a Gramme machine arranged for electroplating and worked by a steam engine of (it is stated) two horse-power,* gave, according to Werdermann, the following results:—

“1°. When the current of the machine was distributed between two lamps, the brightness of the light was equal to that of 360 candles. This light was white, and apparently free from the blue and red ray so often perceived in the light of the voltaic arc. It was, besides, perfectly steady.

“2°. By placing in the circuit 10 derivations, each corresponding with one lamp, as shown in Fig. 57, 10 luminous centres could be obtained, each representing about 40 candles. In order to render the action steady, coils *a a a* of small resistance are interposed in each derivation. Under these conditions the resistance of each lamp was 0.392 ohm, and therefore the total resistance of the circuit was only 0.037 ohm.

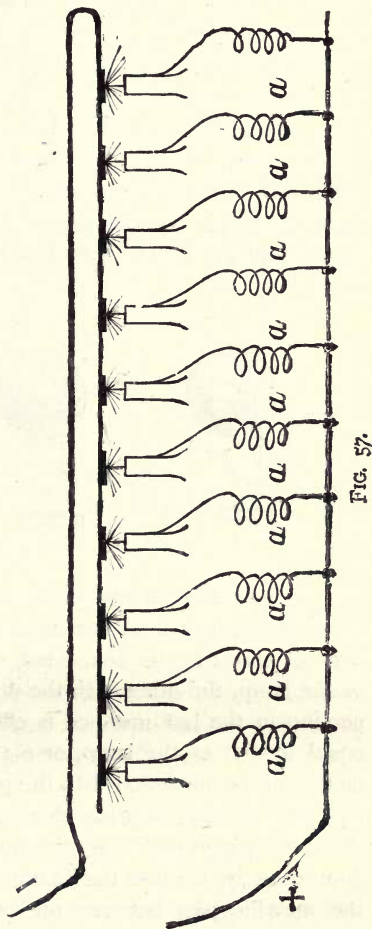


FIG. 57.

* According to the particulars sent to me, this power should be greater.

"3°. The consumption of the carbons in the smallest pattern of the lamps did not exceed 2 inches an hour, and for the large pattern 3 inches. A length of one metre might be used. They were Carré carbons."

With this system, and for that matter with Reynier's system also, all the lamps could be lighted or extinguished at once or successively; and as their brilliancy cannot be great, transparent instead of ground glass globes may be used.

Fig. 58 shows the commutators in each derivation, for throwing into it the resistance a' , for the interruption of the circuit, and for direct transmission; they are metallic rings,

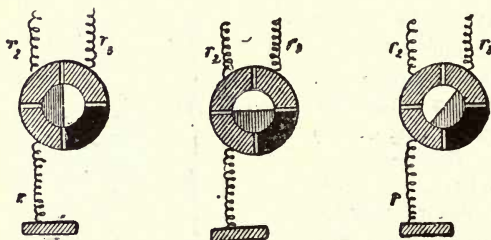


FIG. 58.

divided into 4 segments, within which is placed a plug half of metal and half of an insulating substance. The two upper parts of each ring are connected, one with the lower carbon of the lamp, the other with the upper carbon; but the connection in the last instance is effected through a resistance equal to that of the lamp, or 0.392 ohm. The lower part on the left is connected with the positive wire, and the lower part on the right is made of ebonite. When the plug is in the first position shown in the figure, the current traverses the lamp directly, because the communication is established by the metallic part between the two metallic sectors at the left; when it is in the second position, the current no longer passes through the carbons but through the resistance coil; and as this is equivalent to that of the lamp, there is no change in the distribution of electricity. Finally, when the plug is

in the third position, the circuit is interrupted, and the other lamps benefit by the portion of the current that was previously passing through the lamp.

Besides the resistances just spoken of, there are others placed in the course of the positive wire of each derivation, which are indicated in Fig. 57, and serve to change the brilliancy of any particular lamp.

This system of electric lamp has lately been used in London for lighting the South Kensington Museum, where it is said to have produced a well-spread light of a fine quality, an agreeable softness, and a remarkable steadiness. (See the journal *La Lumière électrique* of the 15th July, 1879, p. 72.)

Some very successful experiments were also made at Paris, in which six to eight lamps were lighted by the current of an *Alliance* machine. It is asserted that it will be possible to light a much greater number with lamps of a smaller pattern and with a particular arrangement of the machine. We shall wait and see the result for ourselves before pronouncing on this matter. We have just learnt that with a Gramme machine, driven by a gas engine of 6 horse-power, it has been found possible to light 15 Werdermann lamps, the carbons of which were 4.5 millimetres in diameter, each lamp giving a light of 25 Carcel lamps. It was, however, a new form of this kind of lamp which gave this result, and this form is not sufficiently known for us to describe it here. (See Note D at the end of this volume.)

Trouve's form of Reynier's Lamp.—Trouvé has just given a new arrangement to Reynier's lamp, which is somewhat that of Werdermann, and at once rather practical and economical. Fig. 59 will give a precise idea of it. The small carbon B, which gives the incandescence, is inclosed in a long tube with a slit all its length, which allows the movable portion D to push the fine carbon against the massive cylinder C under the influence of a counterpoise P pro-

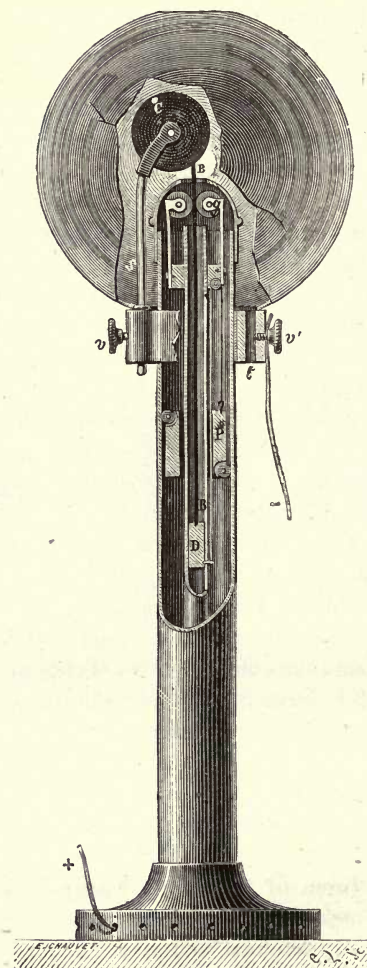


FIG. 59.

vided with rollers. This fine carbon is guided between two spring rollers *g*, which also carry the current to it. The cylinder *c* is of copper, and presents itself to the carbon in

such a manner as to be able to turn by the tangential pressure against it, in proportion as the illuminated rod *BB* is consumed. This lamp works well, and can henceforth be applied to domestic illumination under the influence of a current from 6 Bunsen cells. The rod of carbon is of a more slender diameter than those used by Reynier.

E. Arnould has lately invented a lamp the arrangement of which is exactly that of the preceding apparatus, but under much less excellent conditions, and yet certain newspapers have not hesitated to announce it as something new.

Ducretet's form of Reynier's Lamp.—An arrangement of the kind just alluded to has also been given to Reynier's lamp by Ducretet. In this form, shown in Fig. 60, the rod of carbon *c m*, instead of being pushed by a counterpoise, is plunged in a column of mercury, filling a long iron tube *T*, which forms the body of the lamp. A cap and an elastic collar *B* guide the rod, and, as well as the mercury, impart to it the positive polarity. A carbon cylinder *H*, supported by a metallic arm *s*, movable in a socket with a regulating screw, allows any required length to be given to the incandescent portion. The current reaches the apparatus by the conductor *t*, and leaves

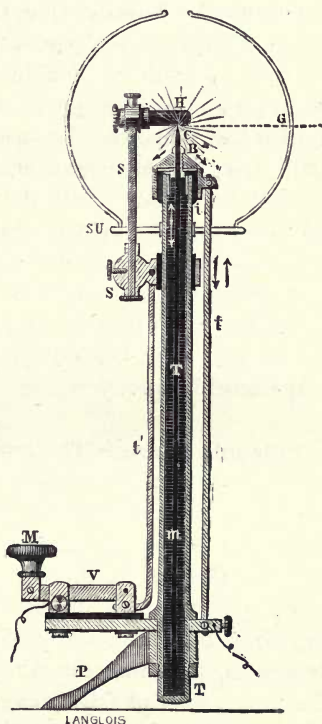


FIG. 60.

it by the conductor t' and the interrupter M v. In order to avoid the poisonous vapours emitted by the mercury in consequence of becoming heated, the cap B is insulated from the tube T by means of a substance not a conductor of heat, and it communicates with the base of the lamp through the copper conductor t , which, being a good conductor of heat, diffuses it and withdraws it from the mercury.

This system, by its simplicity, permits the lamp to be very cheaply made. It had, however, been already devised by Reynier, who had pointed it out amongst the arrangements that might be given to his apparatus.

Tommasi's Lamp.—In order to obtain a longer duration of the working of the preceding lamps, Tommasi arranged them like a revolver. For this purpose, the lamp is formed of an iron tube about 3 centimetres in diameter, turning on a pivot and supporting five carbons of 30 centimetres length, and these, one after another, are by a rotatory movement brought into contact with the carbon disc of the negative pole, and thus the light is produced for eight or ten hours. The forward movement of these carbons is effected by mercury contained in the tube, as in the preceding system, and, according to Moigno, the light thus supplied is very uniform and steady. This lamp has the shape and size of an ordinary Carcel lamp.

Edison's Lamp.—The reputation that Edison acquired by the invention of the phonograph was the cause of considerable financial disasters, when some time ago he announced that he had finally found the long-sought solution of the problem of the division of the electric light. He was taken at his word, and in America, as well as in England and in France, the shares of the gas companies fell enormously. It was forgotten that the American newspapers were often the propagators of false news; and since the phonograph triumphantly refuted the denials with which its announce-

ment was greeted, people ceased to recollect the proverbial *canards Americains*. Be that as it may, this pompous announcement caused many losses, and that at three different times. People have now recovered from their fears, and, as always happens, have passed from one extreme opinion to its opposite. The truth is, that if Edison's invention were at first but a very small matter, it might some day gain importance; and according to the information I have received from ocular witnesses, the last patents of Edison's, which require not less than 200 pages for their description, might contain discoveries of the greatest importance. It seems that even Edison's failures have not discouraged American capitalists, and that they have put at his disposal not only all the necessary amounts, but also engineers of all kinds, electricians, mechanics, chemists, &c. According to the persons who gave me this information, Edison has constructed a dynamo-electric generator superior to all those we have mentioned, and capable of utilizing 90 per cent. of the motive power.

Without attaching too much importance to these accounts, it must be admitted that a man so ingenious as Edison has not for so long a time studied a question without making something of it; and while waiting until the new patents are published, we must meanwhile give some account of the lamp which has fluttered the financial world. It is represented in Fig. 61.

According to Edison, the loss which is involved in the division of the electric light is not peculiar to this kind of light, but also occurs with gas when the elements of its flow are placed under the like conditions. Thus, if a great number of gas-jets are opened and the total amount of light measured, a smaller luminous intensity will be found than that resulting from a small number of these jets under the same pressure of gas. But if that pressure be suitably regulated, things may be so arranged that this loss would not exist. "Now," says Edison, "properly arrange the condi-

tions of the flow of the electric current, and you can do for electricity that which has been done for gas." This reason-

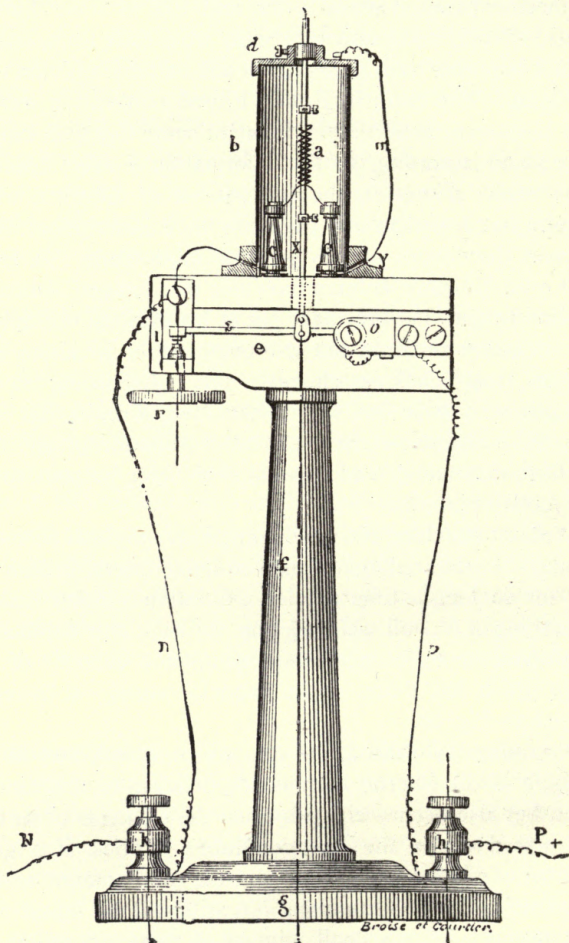


FIG. 61.

ing is correct only up to a certain point, for the conditions of maximum intensity of a current with or without derived

currents are well known, and the arrangement of the generator in any given case is indicated perfectly by Ohm's formulæ. As regards this matter, we do not think that Edison can discover anything more than we know already; and we believe that it is rather by the material arrangements of his lamp that he will have any chance of arriving at the solution he is seeking. Now Edison's lamp, which has many very different forms, consists of the following:

The principle of the lamp, which is represented in Fig. 61, is the incandescence of a spiral of platinum wire *a* alloyed with iridium. And in order to prevent the spiral from burning when its temperature exceeds a certain point, Edison places within the spiral a metallic rod *c*, which by dilating causes a contact to be made at *i*, by means of the lever *s*, precisely at the moment when the heat is about to reach that degree. The current is then *derived* through this contact, and immediately lowers the temperature of the spiral, which causes a disjunction of the derivation and arrests the cooling. The spiral then begins again to be heated, and is thus maintained at a temperature which can vary only between very narrow limits, which may be regulated by the greater or less separation of the contact piece *i* of the derivation, by the resistance of the derivation, or by a resistance regulator variable with the pressure, based on the principle which Edison has applied to telephonic transmitters.

Can a platinum spiral by this means acquire a temperature sufficiently high to produce light? This appears the more doubtful from the fact that De Changy did construct a very ingenious regulator under similar conditions, and that, nevertheless, his spirals were volatilized when they were heated to such a point as to become luminous.

It is true that, according to the American journals, Edison has discovered a new metallic alloy, having its fusing point much higher than that of any known metal.*

* According to Edison's last patent, the incandescent spiral is formed of platinum and iridium, and is covered with a metallic oxide, either of cerium,

Automatic lighter of Reynier's Electric Lamps.—

To avoid the inconveniences which may result from the extinction of an electric lamp—an extinction which may involve that of all the rest of the lamps in the same circuit—Reynier arranges an automatic system of permutator, the effect of which is to light other duplicate lamps placed in the neighbourhood. This system consists of a kind of electro-magnet relay which sends the current of one circuit into another, when the armature of this relay, being no longer attracted, touches its limiting stop. If for this purpose two duplicate lamps are used, as Reynier proposes, these lamps are introduced into two derivations of equal resistance arranged between the two conductors of the generator, and the relays which are to act in these lamps are interposed in the circuit of the first lamp: the contacts of these relays are also arranged so as to establish the communication of the derivations with the circuit at the separation of each relay. When the first lamp is lit, the electro-magnets of the relays being active, the communications of the derivations with the circuit are severed, and the lamp works alone; but if the latter should be extinguished, either by the consumption of the carbons or by accident, the current is immediately sent into the derivations; but as there is then but one relay which is active, there is only one of the duplicate lamps at work, and it is only when this one is in its turn extinguished that the third is lighted.

This system may readily be arranged to suit the various ways in which the luminous central arc is connected with the principal circuit.

zirconium, calcium, magnesium, or of some other metal—*i.e.*, an oxide not altered by a high temperature. The effect of this covering is designated by Edison by the name of *pyro-insulation*, and in order to cover the wire it suffices to dip it into a solution of one of these oxides, then into an acid, and to pass the spiral through the flame so as to evaporate the aqueous portions and leave only the oxide on the wire. (See the *Telegraphic Journal* of 15th July, 1879.)

ELECTRIC CANDLES.

Jablochkoff's electric candles, which have lately been so much spoken of, are certainly not the ideal of the electric light; but on account of the absence of all mechanism, and the comparative regularity of their action, they can be applied to public illumination, and assuredly this could not have been done with any electric lamp invented up to that time. It is they, and the influential company working the invention, that have enabled those beautiful experiments to be undertaken, and those splendid illuminations to be made of the *Avenue de l'Opéra*, of the *Arc de l'Étoile*, of the *Chambre des Députés*, of the shops of the *Louvre*, of the *Théâtre du Châtelet*, &c., which astonished all the visitors to Paris during the Exhibition of 1878, and proved that electric lighting was not the chimera that those interested in gas companies wished to think it. It was the Jablochkoff lamps that excited that rage for electric lighting in every country, which will, as sure as fate, shortly lead to the substitution—or at least the partial substitution—of gas illumination by electric illumination. These candles are, moreover, much used, being now daily lighted in more than 1,500 lamps. We must therefore devote a long chapter to them.

If two perfectly straight carbons are placed side by side parallel to each other, and separated by an insulating layer capable of being fused or volatilized by the passage of the electric current between the two carbons, a lamp without machinery is obtained, which gives light like a candle, that is to say, it burns progressively until the two carbons are entirely consumed. This is the principle of the Jablochkoff candle represented in Fig. 62.

Numerous experiments have been made to ascertain what is the best insulating material to place between the carbons,

and what are the best dimensions for them. After many trials, preference has been given to plaster of Paris as the insulator, and to Carré's carbons 25 centimetres long and 4 millimetres in diameter. When giving a light equal to from 25 to 40 gas-jets, these candles will last for one hour and a half; but we shall presently see that by a



FIG. 62.

very simple arrangement the light founded on this system may be made to last as long as may be desired. A Jablochkoff candle is, then, composed of two insulated Carré carbons *c, d*, 25 centimetres long, slightly pointed at their upper extremities, and separated by the insulator already mentioned, provided at its upper end with a thin layer of lamp black for conducting the current when the candle is first lighted. This layer is made of black lead mixed with gum, and the candle is charged by merely dipping its end in the mixture. At first the two carbons were connected by a plumbago point kept in its place by a piece of asbestos paper; the preceding plan is now found to be much simpler. At the lower end the carbons are fitted into copper tubes, by which they are connected with the circuit when the candle is placed in the chandelier; these tubes are inserted in the piece *M* (made of a silicate or other suitable substance) so as to prevent the carbons from separating from their insulating partition. Before the manufacture of Carré's candles was established on the large scale, a candle like this cost 75 centimes, a rather high price; but now that the cost of these carbons

is much less, the candles can be made at a cheaper rate—perhaps they may some day be had for 20 centimes. We cannot now calculate the cost of the electric light on the data which served for the estimates of the early experiments.*

* Already the Company sells these candles to private persons at 50 centimes.

The manufacture of these candles, which is conducted on the large scale* at No. 61 *Avenue de Villiers*, is very interesting, especially the way in which the insulators are made. A thin layer of sculptors' plaster mixed with sulphate of barium, and so tempered as not to set quickly, is spread upon a marble table slightly oiled, by means of a mould made of a notched plate of zinc fitted into a sliding handle. By drawing this mould along, the plaster in front of it is spread on the marble in the form of grooves and projections to the length of about 2 metres. When the mould has been passed along several times, a fresh quantity of plaster is placed in front of it, which increases the thickness of the projections, and after five or six operations of this kind these pro-

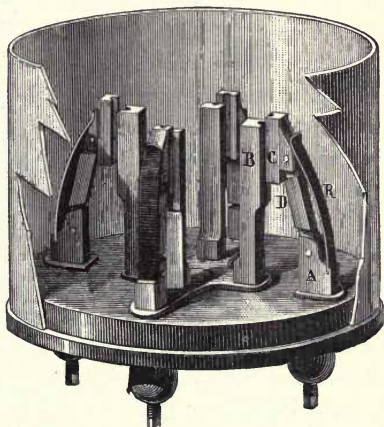


FIG. 63.

jections have exactly the thickness of the teeth of the mould which is that suitable for the insulators. The sides of the insulators are, of course, made slightly concave to receive the cylindrical carbons. Their thickness is generally 3 millimetres between the carbons, and only 2 millimetres in the other direction.

Fig. 63 shows the way in which the Jablochkoff candles are held in the lamp. There are places for four in the figure, but the number may be larger; the lamps in the *Place de l'Opéra* can hold twelve. Each support consists of

* Six or eight thousand are made per day.

two brass uprights, one of which A c is double-jointed, and ends in a shoulder c that will exactly fit the piece to be placed between it and B. A strong spring R presses c towards B. The two pieces B and c are provided with cylindrical grooves which receive the metallic terminals of the candle. As these pieces are electrically insulated from each other and provided with binding screws, it is easy to connect the two carbons into circuit.

Several plans may be used for obtaining continuity of illumination; the simplest and best is to connect one of the terminals of each lamp to a commutator, so that, after the combustion of a candle, the current may be made to pass into the next one by simply turning a handle. This commutator, in the apparatus at the *Avenue de l'Opéra*, is placed within the support of the lamp, and an attendant comes every hour and a half and turns the handle. This commutator is double, in order to make a double change, when two candles are burnt in the same lamp, as in the lights at the *Place de l'Opéra*. The construction of the apparatus is very simple; it consists merely of a wooden disc on which are fixed in a circle as many metallic plates as there are candles; a handle with a spring turns on a metal pillar in the centre of the disc, and the spring pressing against the plates establishes a connection between the central pillar and the plate connected with such candle as may be required.

Besides this plan several automatic arrangements have been invented, but they have not been generally adopted in practice, which has retained the commutators just described. One of these arrangements, represented in Fig. 64, consisted of a bent lever M O *m* turning at o and carrying at one end the platinum wire *f* leaning against the insulator of the candle A' B', and at the other end provided with a contact piece M, which, by touching another piece P, closed the circuit through the next candle A B. A spring *r* acting on the lever kept the wire *f* (by which the contact of M and P was prevented), pressed against the candle; but when the

candle was consumed down to the wire, the latter was no longer supported, and the lever turned until M and P were brought into contact. As each candle was provided with a similar apparatus, the current was transferred successively from one candle to another, without any intervention.

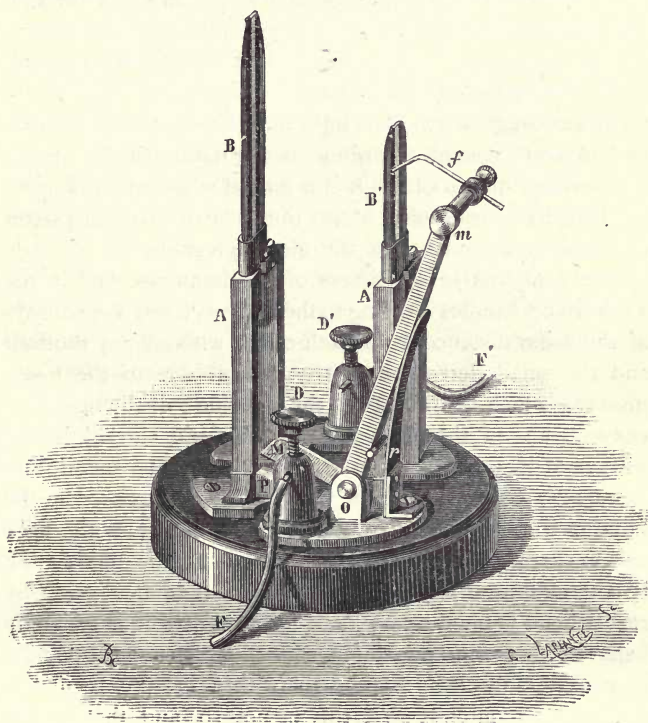


FIG. 64.

In another plan, the change was effected by an electro-magnetic escapement with clockwork, which came into action when the current was interrupted by the extinction of any of the candles, or by a touch from an attendant.

Jablochkoff has, however, lately discovered that no me-

chanism need be used to obtain the successive lighting of the candles. When the circuit connections are made simultaneously through all the candles, one of them will always transmit the current more readily than the rest, and that particular one being lighted by the heat developed, the current will pass almost entirely through the arc, the loss through the other candles being quite insignificant.

The light given by the Jablochkoff candles is very uniform, at least so long as the Gramme machines which supply them work regularly. This light may, however, have a more or less white colour, according to the nature of the insulator between the carbons. If this insulator is made of kaolin, the light has a somewhat bluish tint; if it is made of plaster of Paris, the colour is rosy and more agreeable.

The comparative steadiness of the luminous part in the Jablochkoff candles is owing to the carbons being kept always at the same distance from each other, without any motion, and the small derivation of the current due to the fused insulator which contributes to the steadiness of the light. In consequence of this derivation, the electric current is less weakened than when the carbons are separated by air, and therefore a larger number of lights can be interposed in the same circuit. The flame, too, which accompanies the light appears to enlarge the luminous focus, so that the illumination is better diffused and with less shadow than that given by regulators. Opinions vary as to its intensity; it is generally believed that with equal currents the light of the candle is considerably less intense than that of the regulator. Jablochkoff contends that this is not so, and that in the experiments of comparison from which this conclusion was drawn, the candle was under less favourable conditions than the regulator, which automatically adjusts itself for the best effect. In support of this statement, he mentions the experiments made by Fichet, one of the jury at the *Exposition*, who, in order to remove any doubt in the matter, proceeded as follows:—After having measured the illuminating power of a

candle having carbons of 10 millimetres in diameter, he placed the same carbons in one of Serrin's regulators, adjusted so as to give the same length of arc. The conditions thus being the same in each case, he found that the luminous intensity was also the same; and he points out that the heat employed in volatilizing the insulator was not entirely lost, as is generally supposed. With certain insulators, particularly with kaolin, there may be, according to Jablochhoff, some diminution of light from the somewhat considerable derivation of the current through the fused part of the insulator; but with plaster insulators this inconvenience does not exist, and above the candle there is a flame, which he considers useful. Be that as it may, these candles are not exceptional in being attended with a loss of electricity, for in the regulators there is also a loss of current, due to the introduction into the circuit of a coil of more or less resistance. But we have seen that the Lontin arrangement, by derivation, in a great measure avoids this inconvenience.

The Jablochhoff candles require to be used with alternately reversed currents; and we have seen that to obtain such from the Gramme machine it was necessary to invent a special machine, which at the same time would allow the action to be distributed over several circuits. It is easy to see why the currents must be reversed, if we remember that with direct currents one of the carbons (the positive one) would be consumed quicker than the other, and the distance between them would gradually increase, until it would become so great that the light would go out. Jablochhoff asserts, however, that this may be prevented by increasing the diameter of the positive carbon sufficiently to make it burn as slowly as the other. This plan has not hitherto been tried.

In order to obtain a slower rate of consumption, Jablochhoff has lately used metallized carbons. We have seen (p. 137) that this plan, which was invented by Reynier, has given excellent results, and in experiments recently made at Geneva the candles were thus prepared. The metal was, however,

removed from the parts of the carbon in contact with the insulator. We are told also that in America this metallization was not deemed sufficient, and the carbons were further covered with plaster to keep the metal from oxidizing—apparently not without advantage.

We have seen that to light the Jablochhoff candles the current must first be passed through a secondary conductor. When the arc is once established, this secondary conductor is volatilized, and nothing more remains by which the candles could be lighted again if they went out. This would be an inconvenience if there were not at hand a commutator and candles in reserve. But Jablochhoff has contrived a plan by which there is a secondary conductor between the carbons when the arc is extinguished. He mixes very fine copper filings with the insulating plaster, and when the latter is volatilized these are also vapourized; and when the light is extinguished, the copper deposited on the insulator is a sufficiently conductive layer to re-light the candle.

An enamelled glass globe is used with the Jablochhoff candles when these are applied to public lighting, and then the apparatus has the appearance shown in Fig. 65, where part is in section and part in elevation. This arrangement, however, causes a great loss of light, for 45 per cent. is stopped by the globe. It is true the light thus diffused is advantageous for lighting, but these contradictory conditions may be satisfied by using, instead of the globes, double reflectors: for instance, a kind of funnel of ground glass surrounding the candles below and above a hemisphere of translucent glass; above this should be placed a reflector of enamelled glass or porcelain, which will send down again the luminous rays reflected by the internal surface of the funnel. The electric light globes are, however, now being improved. Paris has made them of opaline glass, absorbing only 35 per cent. of the light. At Baccarat, globes have also been made of frosted glass, which have only a comparatively small absorbing power, and this absorption may be reduced to 10 per cent.

by using a globe of waved or wicker-work glass. Clémandot has also made globes of transparent glass in which the diffu-

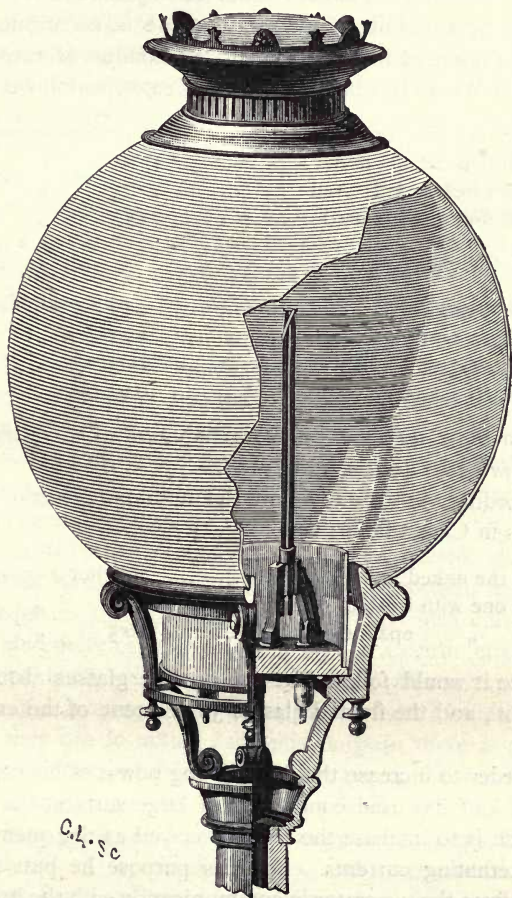


FIG. 65.

sive effect is produced by a layer of fragments of glass placed between two spherical surfaces one within the other. These globes absorb, according to the maker, only 25 per cent. of

the light ; but it may be feared that some inequalities may in time occur and destroy the uniform diffusion of the light.

The expenditure of motive power for 20 Jablochkoff candles worked by a dividing Gramme machine is, according to a Report presented in May, 1879, to the London Metropolitan Board of Works by Bazalgettes and Keates, as follows :

With only one circuit used	...	...	13'17	horse-power.
With two circuits used	...	...	17'91	"
With three circuits used	...	...	20'75	"
With four circuits used	...	...	23'53	"

And for each candle

With 5 candles	...	...	...	1'59	horse-power.
With 10 candles	...	...	...	1'27	"
With 15 candles	...	...	...	1'03	"
With 20 candles	...	...	...	0'92	"

From these numbers the work required to drive the machines *in vacuo* has been deduced.

According to the same report, the luminous power of these candles in Carcel lamps is :

For the naked light	...	...	...	39'8	horse-power.
For one with frosted glass...	...	...	...	27'9	"
„ opaline glass...	...	...	...	16'5	"

Whence it would follow that the opaline glasses absorb 59 per cent., and the frosted glasses 30 per cent. of the emitted light.

In order to increase the illuminating power of his candles, Jablochkoff has used condensers of large surface, the effect of which is to increase the tension as well as the quantity of the alternating currents. For this purpose he puts a conductor from the generator in communication with the homologous armatures of a series of condensers, the other armatures of which correspond separately or collectively with the different candles connected with the generator. Both for quantity and tension the effects are superior to those pro-

duced by the action of the generator simply, and this is proved in the manner following :

If in the path of the current from an alternating-current machine capable of giving a spark equal only to that of 6 or 8 Bunsen elements, there is interposed a series of condensers of about 500 square metres in surface, a voltaic arc of from 15 to 20 millimetres length may be produced, and carbons of 4 millimetres are made incandescent for a length of 6 or 10 millimetres from their extremities. Also, if in the current of an induction coil supplied by an alternating current, and giving a spark of 5 millimetres, there is interposed a condenser of about 20 square metres of surface, a voltaic arc of 30 millimetres may be obtained ; and in this case also carbons of 4 millimetres in diameter are made incandescent for a length of 6 or 10 millimetres from their extremities. Finally, a certain number of condensers being given, if the second surfaces of one or of several of them are joined with the second inducing coil of the machine, or with the earth, there will be produced in the apparatus arranged as before effects much resembling those of static electricity.

These effects are what might have been expected, and it was by similar means that Planté, with his rheostatic machine, succeeded in transforming voltaic currents into currents of static electricity capable of giving sparks 4 centimetres long.

Jablochkoff's system of condensers supplies a very simple means of regulating the intensity of the light of the candles while they are in action ; for this purpose there is needed merely a commutator by which a greater or less condensing surface may be connected with the circuit.

Each of these condensers when applied to public lighting is made of 25 separate elements, and corresponds with a group of four candles ; consequently, these four candles are connected with one of the wires proceeding from one of the armatures, and the circuit is of course interrupted at the condenser. It may therefore be inferred that the current which supplies the candles is only a current of the return discharge

resulting from the condensation, and that therefore it should exhibit the effects of discharge of static electricity. It is for this reason that, instead of the four candles which may be introduced into each of the four circuits of a Gramme division machine, eight may be placed in each circuit ; but it is necessary that the condenser attached to each group of four candles should have an extensive surface, and to attain this each element is made of 32 of the largest sized sheets of tinfoil. Under these conditions the light of each candle appears of undiminished intensity. It remains to be seen whether the generator does absorb a greater amount of motive power ; but no experiments have yet been made on this point.

According to Jablochhoff, the use of these condensers, which, after Warren de la Rue, he calls *exciters*, is indispensable for obtaining electric lights by derivations of the current. When the experiment is tried without the condensers, it is found that the lamp which offers the least resistance absorbs so much of the current that in a few minutes the others are extinguished. If the derived circuit had a perfectly uniform resistance, satisfactory results might perhaps be obtained in this way ; but there are so many causes for variations of resistance, that it is impossible to reckon on such a uniformity continuing for any length of time. It is only in these condensers that the solution of the problem has been found, at least as regards electric candles.

The condensers used by Jablochhoff are of a very great size, and they take up a comparatively large space. For a series of four candles they form, as we have seen, a pile of 25 elements, of about 75 centimetres high, 80 long, and 50 wide, but do not require any particular position, and may be placed in any convenient place. They are made of sheets of tinfoil, separated by thin layers of sealing-wax, or by varnished silk, or by paper covered with paraffin.

The Jablochhoff candles are now very largely used. In Paris they are set up in four large drapery shops ; at the *Besselièvre* and *De la Scala* concerts ; at the *Théâtre du*

Châtelet and the *Hippodrome*; at the workshops of Messrs. Crespin and Marteau, of Messrs. Veyher and Richemond, of Messrs. Corpet and Bourdin; in the *Passage Vivienne*; at the mansion of the Queen of Spain, and of M. Menier; at the Continental Hotel, the Figaro Hotel, the *Brasserie Moderne*; Christophe's show-room; Lemaire, the optician's shop; at the Giffard balloon, &c.; besides the other places which have been previously mentioned.

In the provinces this system of lighting is used in 26 establishments of various kinds, and abroad it is used in scores of cities, such as London, Madrid, Lisbon, Birmingham, Stockholm, Copenhagen, Amsterdam, Ghent, Seraing, Blankenberghe, La Croyère, Zurich, Geneva, Berlin, Neugersdorff, Königsberg, Frankfort, Duren, Munich, Chemnitz, Lemberg, Breslau, Brieg, Eberfeld, Vienna, Brünn, St. Petersburg, Monte-Carlo, Milan, Rome, Naples, St. Louis (Missouri), San Francisco, Mazatalan, Teheran, Rio de Janeiro.

According to a statement just published by the Jablochhoff Company, the cost of their system of apparatus amounts to 9,004 francs for 16 candles, 5,562 francs for 8 candles, 4,666 francs for 6 candles, and 3,852 francs for 4 candles.

Other Systems of Electric Candles.—In order to avoid the loss of heat caused by the fusion of the insulator, which some think prejudicial for the light, several inventors—among the rest, Rapiéff, Siemens, De Méritens, Soligniac, Jamin, Thurston, Wilde, &c.—have devised electric candles in which the insulating substance is replaced by an air space. In Wilde's recently-patented system, which is represented in Fig. 66, the two carbons are fixed side by side vertically in metallic holders, but one of them is slightly inclined towards the other, and its holder turns on a fixed support, and is provided laterally with a piece of iron, which forms the armature of an electric magnet. The antagonistic spring of this armature is so regulated that the electro-magnetic action shall preponderate only when the carbons touch

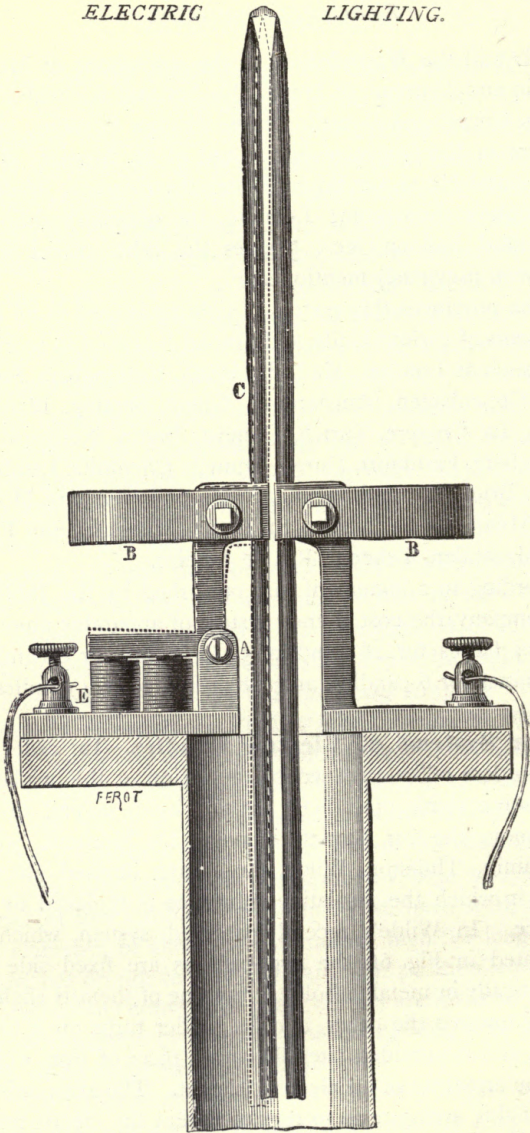


FIG. 66.

each other, and then it causes a greater or less separation which can be maintained, for the movable carbon is subjected during the whole time of its combustion to two opposite effects, which keep it always in a position more or less near the fixed carbon, from which position it can vary only a very little. This arrangement seems very nearly the same as that which Rapieff described in the *Telegraphic Journal* of the 15th December, 1878, and the 1st February, 1879. It remains to be seen who is entitled to the priority. The Méritens system is composed of three parallel carbons not in contact. The current passes in the outside carbons, and the middle one is merely the means of facilitating the discharge and rendering it uniform. Nevertheless, this system has not given regular results; but that of Soligniac, in which four carbons are used, has been much more satisfactory, and we shall speak of it further on. The important condition in all these systems is that the two carbons shall never be able to assume a perfectly parallel position, for in that case the luminous point may be displaced, and pass from one end of the carbons to the other.

One system has been proposed in which the carbons are inclined and applied one to the other, until they are lighted by being separated by a rod of refractory matter introduced between them, the movement being controlled by an electromagnetic action.

Jamin's Candle.—Of the electric candles invented since the Jablochhoff, none has attracted more attention than the Jamin burner, which is represented in Fig. 67. It is a candle of the same kind as Wilde's—that is to say, there is no insulator between the carbons. The luminous point is constantly maintained at the end of the carbons by the action on the arc of the current itself passing through a conductor beneath the arc, and returned on itself four times, forming a rectangular figure about the carbons. Two parallel currents in the same direction, as we know, attract each other, and therefore it will be understood that the arc is attracted by the

part of the current passing below it, that it will tend to move towards the fixed conductor, and consequently will be kept at the end of the carbons. Jamin thus describes his invention in a note laid before the *Académie des Sciences* on the 28th April, 1879:

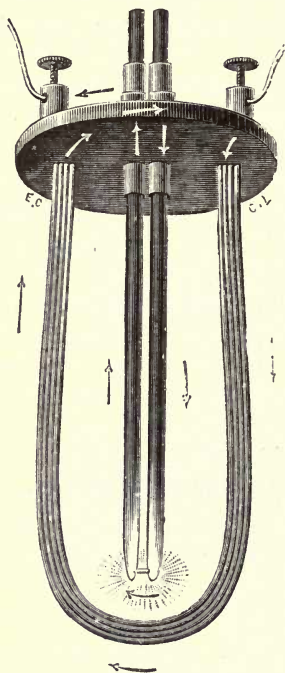


FIG. 67.

"I have the honour of presenting to the *Académie* a model of an electric burner reduced to the greatest possible simplicity. The two carbons are kept parallel by two insulated copper tubes, separated by a space of 2 or 3 millimetres; they slide with friction in these tubes, which serve at once to keep the carbons in their places and to convey the current to them. The carbons are surrounded by a circuit of five or six spires wound on a slender rectangular frame 40 centimetres long and 15 wide. I have explained how this circuit, traversed by the same current as the carbons and in the same direction, brings the arc to the end of the carbon points and keeps it there.

"The lighting is done automatically. For this purpose the two ends of the carbons are surrounded by a thin India-rubber band, which presses them together; then a little higher a small

fragment of iron wire is placed between them, which puts them into close communication at a single point. As soon as the circuit is closed, the current passes through this wire, heats it to redness, and melts the India-rubber; the two carbons being liberated now separate, and the arc is established with a kind of explosion. Carbons of any thickness up to 8 millimetres may be used. With this size the consumption scarcely exceeds 8

centimetres per hour. As it proceeds, the points get near to the supporting tubes ; but from time to time they can, without extinguishing the light, be restored to their original position by simultaneously sliding the two carbons in the tubes. In future a mechanism easy to imagine will perform this duty, and as Carré makes carbons 1 metre long, the lamp may continue lighted for twelve hours, a period longer than will ever be required. It will be observed that the carbons are not separated by any insulating material, and that it is not necessary to point them beforehand, or to fix them at their base, or to tip their ends with any inflammable material. They are used as they leave the manufactory. It suffices to put them into the tubes that hold them, and leave them to the directing action of the exterior circuit. There is, in fact, no candle to be made, it is merely a putting in its place of a sort of match which burns by itself to the end.

“The apparatus may be hung up in two ways, with the points upwards or directed towards the ground. The conditions are very different. Let us examine the first case.

“The electric arc cannot, without breaking, exceed a length, which depends on the intensity of the current. Between two carbon points in a horizontal line, it should be straight, because according to the laws of electric conduction, it takes the shortest course and tends to return to that by virtue of a kind of elasticity if withdrawn from it. But it is interfered with by the ascending current of air generated by its own heat ; and for that reason assumes the curved form. It is still more strongly interfered with by the directive circuit (in the carbons), and these two actions combine to curve it upwards until equilibrium is attained between them and the elasticity (as it might be termed) of the arc ; but they also cause it to become longer, they lessen its resistance to rupture, and diminish the intensity of the current. We see, then, that if they concur in fixing the light at the points of the carbons, it is on the condition of diminishing the limit of length attainable by the arc, or, what amounts to the same thing, the number of arcs that a given machine will maintain.

“It is quite a different thing when the points are turned downwards. While the arc tends to rise up along the carbons, the directive circuit drives it back, and brings it down between the points, which have an interval of 7 or 8 millimetres between

them. The two actions which formerly combined now oppose each other ; so far from lengthening the arc, they shorten it ; instead of lessening its resistance to rupture and diminishing the intensity of the current, they increase both.

“ This arc may be said to be compressed between two opposite actions ; it is shorter, narrower, less expanded, denser, and consequently hotter, and the number of the lights may be increased. The Jablochkoff candles, otherwise so well arranged, possess the inconvenience of having their points upwards. The arcs they form naturally tend to curve and rise up, a tendency which is strengthened by the electro-magnetic action of the current ascending in one carbon and descending in the other : an action identical with that in my directive circuit, though smaller in amount. The burners with the points downwards should therefore surpass these candles, as, indeed, experience proves. With a machine which is sufficient, with difficulty, to light three candles, I easily supply five burners, fitted with much larger carbons, each burner giving twice as much light as a candle ; and as the points are immersed in the mass of the arc, they are more brilliant and of a much whiter colour. Even six lamps may be lighted, but they give a sum total of light less than five do ; the number may be doubled, but there is a loss in the quantity of light. It is always thus when we try to divide the electric light beyond a certain extent ; the division is purchased by a proportional loss.

“ It is interesting to examine the behaviour of these burners. When the points are upwards, the first lighting is very difficult, because the arc is at once briskly thrown upwards by the influence of the directive current, which is proportional to the square of the intensity. When this increases it becomes absolutely impossible to light the carbons ; we get nothing but a great flame, which immediately disappears with a snap. If the current is weaker the light remains, but very diffused, very high, and always very noisy, on account of the oscillations which take place on each inversion of the current. Again, the equilibrium is unstable ; if an accidental current of air for an instant raises the height of the arc, it cannot be brought back ; the limit of its elasticity is exceeded, and it immediately breaks. In the burners with the points downwards the lighting is easy and the equilibrium stable, for if a movement of the air, or a failure, causes the

arc to rise, it is established between the two carbons at the place where they have not been worn away by combustion ; it takes up a position where the interval does exceed 2 or 3 millimetres. So far from being lengthened, it is shortened ; and instead of being lessened, the resistance to rupture and the intensity of the current are increased, and the light is seen to quietly come down again, and resume its position at the extremities of the carbons ; if, on the contrary, the current increases, the arc bends and becomes concave towards the carbons, but its tendency to rise counterbalancing the action of the directive current, it is never sufficiently elongated to break. The best economical conditions are obtained when this curve is just sufficiently marked to prevent the upward movement of the arc. In this case the inevitable noise of the electric light is reduced to its minimum, because the amplitudes of the vibratory movements are the smallest possible.

“In short, the burner I submit to the *Académie*, with its points downwards, realizes considerable advantages :—1°. Simplicity, since it involves no mechanism, and needs no preliminary preparation ; 2°. mechanical economy, since the number of lamps may be doubled ; 3°. increase of light, since each of the new lamps has double the power of the old ones ; 4°. quality of light, which is whiter ; 5°. a better arrangement of the lamps, which throw the greater part of their light downwards, instead of towards the sky, where it is useless ; and 6°. economy of the combustibles, since the consumption is less on account of the thickness of the carbons. All this forms a marked progress in the electric light, and cannot fail to strengthen the hold it has already taken on public illumination, thanks to Carré's carbons, to Jablochkoff's candle, and to the progress made in machines.”

Jamin has quite recently added to his burner an electromagnetic arrangement which, as in Wilde's system, enables the candle to be automatically lighted, and prevents its extinction. For this purpose he makes the upper part of the multiplier that surrounds the candle, where it passes above the plate by which the system is supported, go between the branches of a plate of iron bent into a horseshoe form ; these branches consequently constitute while the current passes

two poles capable of attracting soft iron armatures. These armatures are provided with stops and with opposing springs, and are each attached to a jointed arm placed in a different direction, and connected on either side with one of the carbon-holders. Now it follows from this arrangement that each current sent out of the machine produces a double attraction, and gives rise to a movement that becomes vibratory by reason of the rapid succession of the currents, and this movement, by bringing the carbons nearer to and further from each other, keeps them continuously lighted. This movement may moreover be more or less marked by means of the stops and springs of the armature. (See, for details of this arrangement, the journal *La Nature* of the 20th September, 1879.)

The company which manufactures the De Méritens machines now devotes some attention to fabricating carbons for the electric light, and candles of a new form invented by Soligniac, which, it seems, yield very good results. These candles have four carbons of unequal diameter, separated from each other by an interval of half a millimetre, are connected together in the same plane by two insulating and volatilizable bands. The two outside carbons have a larger diameter than the others (4 millimetres), which are only $2\frac{1}{2}$ millimetres in diameter; the outside carbons are, moreover, fitted into copper sockets, by which the electric communication is made with the lamp. Finally, the four carbons are at their bases connected by plaster of Paris, which occupies all the space between the two sockets. It appears that candles on this plan can only work well with four carbons, and that those in which only three are used must be abandoned.

We have seen (p. 139) that Alkelmer sought to diminish the resistance of electric carbons by introducing metallic plates between the sides of the insulator and the carbons. Now these plates also possess, according to him, the very great advantage of enabling the candle to be automatically

re-lighted; but in that case it is necessary that the insulator should be made of a moderately conducting substance, the resistance of which is calculated accordingly. This arrangement moreover enables the current to make a derivation when the light goes out, and this prevents the generating machine from "running away," as often happens when the resistance opposing its working is suddenly withdrawn. We have seen that Jablochhoff used a similar plan for re-lighting his candles, and I am told his plan was patented a year before that of which we are speaking.

In order to keep the luminous point stationary in electric candles, the Abbé Lavaud de l'Estrade has contrived a kind of candlestick in which the candle is supported by a float. For this purpose the candlestick has three vertical rods, two of which terminate in cylindro-conical vessels plunged into two tubes filled with mercury. The third rod serves as a guide, and a rack enables the mercury tubes to be placed at any suitable height. The object of the vessels is to keep the electric candle at any given height, and their capacity, as well as the volume of the rods which they supported, are calculated accordingly. This height may, it is true, be modified by means of the rack, but the equilibrium between the weight of the candle and the tendency of the vessels to rise up being always the same, so long as the candle keeps its weight the vessels are immersed to the same extent, whatever may be the position of the system supporting the candle. It is only when the candle comes to be consumed that this equilibrium is destroyed and the candle rises, the amount being determined by the relation between the volume of the carbon consumed and that of a cylinder of mercury having a diameter equal to that of the rods and the weight of the carbons consumed. If the rods attached to the vessels have such a diameter as that the weight of the mercury they displace precisely corresponds with the weight of the carbon consumed, and such that the height they project from the mercury shall be exactly the same as that by which the carbons are short-

ened by their combustion, the luminous point will remain at the same elevation, and the electric candle may thus be used for projecting images on a screen like the electric lamp with clockwork movements. Lavaud de l'Estrade points out yet another arrangement for obtaining the same effects with Wilde's candle, but these apparatus are not yet sufficiently practical for us to dwell upon them.

Other systems of electric lights have been proposed, and we should never have done if we considered all the more or less fanciful ideas which have been advanced. To give a notion of their value, we need but allude to the method mentioned in certain newspapers, of covering the walls of rooms with fluorescent and phosphorescent substances, which, according to these projectors, will in the daytime store up light sufficing to illuminate the rooms by night. This simple notice will serve to show how far the imagination will run when it is not controlled by a wise theory.

At the exhibition of electric light in the Albert Hall, at London, in 1879, more than 25 different electric lamps were on view. There were, in the first place, specimens of all that we have described; and besides, there was a new form of incandescent lamp, contrived by Higgin, which was very similar to that of Ducretet, and in which use was made of mercury to push on the movable carbon in proportion to its rate of consumption.

PART IV.—COST OF ELECTRIC LIGHTING.

The expenses attending electric lighting are of various kinds, and belong, independently of the first cost of the apparatus, to—1°, the production of the electric current; 2°, the combustion of the carbons. It is true that for a long time little attention was paid to this last expense, because it was so small in comparison with the other. But now when, thanks to induction machines and thermo-electric piles, electricity can be cheaply produced, it has become important, and may reach a higher figure than the other, especially with electric candles.

At various times important investigations have been made regarding the cost of the voltaic arc, either with batteries or with induction machines, and we are going to give the briefest possible summary of them, although it must be confessed that they are not yet sufficiently conclusive to be implicitly relied upon.

Cost of the Electric Light with Batteries.—In an interesting Report presented in 1856 to the *Société d'encouragement*, Ed. Becquerel states that when applied to the production of a voltaic arc, a Bunsen battery of 60 elements, having zincs 20 centimetres high by 8·5 centimetres diameter, and porous vessels 20 centimetres high by 6·5, consumed in 3 hours 956 grammes of zinc and 1,464 grammes of sulphuric acid. This makes the cost about 1 franc per hour. Estimating the expenditure of nitric acid at one equivalent of acid for one of zinc, as shown by experiment, Becquerel estimated the cost of that liquid at 1 franc 46 centimes, which would give a total cost of 2 francs 46 centimes. But, as he points out, the real cost is higher than that, for even if the zinc that remains could be used for other purposes, the nitric acid

lowered from 36° to 25° of the hydrometer will no longer act with sufficient energy to yield the voltaic arc under advantageous conditions. It is also necessary to take into account the loss of mercury, the somewhat greater consumption of zinc than theory indicates, and the consumption of the carbons between which the arc passes, the value of which is 2 francs 50 centimes per lineal metre. "The cost per hour then amounts," says Becquerel, "to 3 francs for the 60 cells, or about 5 centimes per hour for each cell. However, the cost for a given luminous intensity is not the same at the beginning and at the end of an experiment; this results from the diminution in the electric intensity of the cells, that is to say, from the change in the composition of the liquids they contain. It is nevertheless one result which ought to be stated, as it facilitates the inquiry into the price of working a Bunsen battery; it is, that for every 1 franc's-worth of zinc the other materials may be estimated at 1fr. 50, so that the total cost cannot be less than 2fr. 50."

A curious remark made by Becquerel is that the luminous intensity diminishes much more rapidly than the intensity of the current, and this depends upon the fact that the luminous intensity, being a function of the quantity of heat disengaged, must, like it, vary as the square of the quantity of electricity which passes through the circuit in a given time, according to Joule's law. (See page 6.)

"We see," Becquerel concludes, "that according to the determinations I have given, having regard merely to the cost of the substances consumed, and without including labour, the electric light would, light for light, be four times dearer than gas-lighting at the selling price of gas in Paris. It would be the same as that of lighting by oil, and a quarter of that of lighting by candles. But if we estimate the labour required to superintend the apparatus, to get it ready, and to renew the batteries, &c., the cost would increase by at least half as much again the amount mentioned above."

According to experiments made at Lyons during 100 hours

by Lacassagne and Thiers, for the lighting of the Rue Impérial, which required a battery of 60 Bunsen cells, the cost amounted to about 3 francs per hour for a light equivalent to a mean of 50 Carcel lamps (75 at the beginning, 30 at the end), and this cost was distributed as follows :

Substances	Consumed in 100 hours.	Pr'ce.	Total price.	Cost per hour.	Actual cost.
	Kilos.	Fr. per 100 kilos.	Fr.	Fr.	Fr. per 100 kilos.
Zinc	72'00	104	74'95	0'75	80
Sulphuric Acid	154'00	24	36'95	0'37	12
Nitric Acid ...	247'00	70	173'25	1'73	56
Mercury ...	9'00	550	49'75	0'50	650
Purified Carbon	6'61 metres	3 per metre	19'85	0'20	2'50 per metre
	Totals		354'75	3'55	

This cost of 3 fr. 55 c. per hour is nearly the same as that calculated by Becquerel from the actual expenditure.

According to new and very interesting investigations undertaken by Reynier, the cost of the electric light with incandescence lamps may be reckoned as follows for each Carcel lamp per hour :

	Fr. c.
With a Bunsen battery (Ruhmkorff's form) ...	0'122
„ a Thompson battery (large size)	0 062
„ a bichromate of potassium battery, with porous vessels, chloride of ammonium and mercury (Goarant and Tromelin's form)	0'180

In order to obtain a current equivalent to that from 8 Bunsen cells (Ruhmkorff's form), giving a light of from 6 to 12 Carcel lamps, 45 Thompson cells, or 24 Goarant and Tromelin cells, would be required.

It will be seen from these figures that the economical solution of the problem of electric lighting is not to be found in batteries with liquids.

Cost of the Electric Light with Induction Machines.—We have seen that according to the experiments of Jamin and Roger the electro-motive force of the current from an *Alliance* magneto-electric machine with 6 discs, having the bobbins arranged for tension and with a speed of 200 rotations per minute, is equivalent to that of 226 Bunsen cells; but when the bobbins are arranged for quantity, it is equivalent to the current from only 38 Bunsen cells. We have also seen that the resistance of the generator should be considered fictitiously with regard to Ohm's law as being equivalent to that of 665 Bunsen cells in the first case, and to that of 18 cells in the second case. The light produced by that machine was, with the earlier arrangements of it for lighthouses, equal to 230 Carcel lamps; and according to the calculations of Reynaud, Inspector of Lighthouses, the cost of the current was 1 franc 10 centimes per hour.* If this cost is compared with that of the current from a Bunsen battery of the same power, calculated from the data given by E. Becquerel, the economy of using these machines is in the proportion of 1 franc 10 centimes to 11 francs 30 centimes, that is to say, more than tenfold; and the cost of the light, compared to that given by ordinary oil in a Carcel lamp, would be only one-seventh. We must, however, observe that the carbons have not been taken into account.

According to Le Roux's experiments, the cost of the electric light produced by the *Alliance* machines would,

* The cost was distributed as follows:—

						Francs.
Interest of capital expended in the purchase of						
the machines	...	...	...	...	...	0'28
Fuel for steam engine	...	...	...	...	...	0'40
Engineer's wages	...	...	...	...	...	0'35
Lubrication, &c.	...	...	...	...	...	0'07

						1'10

Complete data on this question will be found in the Report of Le Roux (*Bulletin de les Société d'Encouragement*, tome XIV, page 776), and in Reynaud's Paper on the lighthouses and beacons of the French coast (*Paris Imprimerie Nationale*, 1864).

under the most favourable conditions, be 2·4 centimes, and under the most unfavourable, 3·4 centimes per hour for each Carcel lamp, which would nearly correspond with the cost of gas at Paris.

With the new machines the cost is greatly reduced, as the figures given by various engineers for the Gramme machine will show. If this machine is used only where there is a large space to be lighted, and where there is a motor so powerful that the addition of one or more machines does not interfere with its regular run for the workshop, the cost of the electric light is surprisingly small.

“Under these conditions,” says Fontaine, “a Gramme machine mounted on a pedestal costs 1,600 francs, a Serrin regulator 450 francs, and the price of the conductors is according to their length, and about 1 or two francs per metre. The carbons of the regulator cost about 2 francs per metre, and their consumption is 8 centimetres per hour. Now, 500 hours a year of lighting, and 4 apparatus in the same establishment, the annual expenses if a steam-engine is used are :

4,000 kilos. of coal at 35 fr. per ton	...	...	140 fr.
166 metres of retort-coke carbons	...	...	320
Working the machines at 0 fr. 50 c. per hour			250
Sinking of 10,000 fr., at 10 per cent. per annum			1,100
Total			1,810

“If hydraulic power can be used these expenses are reduced to 1,570 francs.

“For a single lamp we must reckon 30 centimes of maintenance per hour, which increases a little the proportional cost. On the other hand, for 8 lamps the maintenance does not exceed 75 centimes, and the proportional price is lessened. Adopting as a basis of calculation 525 francs for each apparatus per year for 500 hours of lighting, we may be certain of being within the mark.

“With the new Gramme machines (form of 1877) and the Gauduin carbons, the cost of the unit of light per hour is reduced by 40 per cent.

"These figures are deduced from practice, and we have never found that they are too favourable: on the contrary, it has in many cases been observed that the cost per Carcel lamp is less than that we have named."

According to the tables given in Fontaine's work, pages 200 and 201, it appears that for the same luminous intensity, the Gramme machine, under the most unfavourable circumstances, would produce a light

75 times cheaper than that of wax candles.

55	"	"	stearine candles.
16	"	"	colza oil.
11	"	"	gas at 30 centimes per cubic metre.
6 $\frac{1}{2}$	"	"	gas at 15 centimes per cubic metre.

Under the most favourable conditions this light would be 300 times cheaper than that of wax candles.

200	"	"	stearine candles.
65	"	"	colza oil.
40	"	"	gas at 30 centimes per cubic metre.
22	"	"	gas at 15 centimes per cubic metre.

The economy in the cost of lighting by fitting up a spinning-mill of 800 looms with Gramme machines, instead of fitting it up with gas, is found to be 33 per cent., and this with six times as much light supplied.

From an interesting notice just published by R. V. Picou, engineer of arts and manufactures, we extract the following particulars, which appear free from all exaggeration in either direction, and which indicate the price of a franc as representing the expense of an electric lamp per hour.

According to Picou, an electric lamp supplied by an ordinary Gramme machine would be able to illuminate from 250 to 500 square metres of a workshop in which minute operations are carried on; 500 to 1,000 square metres of machine-fitting shops, and 2,000 square metres of a work yard.

The expense of fitting-up would be

Gramme machine	...	...	...	1,500 fr.
Serrin lamp	...	...	...	400
Accessories of the above	...	...	...	50
Conducting wires	...	...	...	50
Transmission	...	...	...	50
Carriage and packing	...	...	...	50
Various	...	...	...	100
Total				2,300

and the working expenses per hour would be :

	Fr. c.
Retort carbon	0'21
Coke for motive power	0'15
Working expenses and management	0'10
Sinking of 2,300 fr., divided over 500 hours of lighting yearly	0'49
Total	0'92

If lighted throughout every night, that is to say, 4,000 hours in a year, the cost falls to 53 centimes.

With an hydraulic motor the expenses are 77 centimes for an illumination of 500 hours, and 38 centimes for an illumination of 4,000 hours.

A workshop of 60 metres by 20 will require two lamps, which will entail a cost of 1 fr. 77 c. per hour instead of 3 fr. 50 c., the expense of 100 gas-lights that would have to be used in such a case, and which would give only one-fifth or one-sixth of the total intensity of light.

If the workshop is open all the night, the cost per hour becomes 0 fr. 97 c. with the electric light, and 3 fr. 07 c. for the gas.

It will be interesting to compare these indications with the results that were published in England after the Trinity House experiments, and we give an abstract of these from a paper read before the Society of Civil Engineers of London, by Higgs and Brittle, entitled "*On some recent Improvements in Dynamo-electric Apparatus.*"

“Although under certain circumstances these two agents undoubtedly come into competition, they have two separate fields. Hitherto gas been generally employed for lighting spaces of both large and small dimensions, because a better source of light for large spaces has not been procurable with economy. But for lighting large spaces that are not subdivided by opaque objects or screens, it is a want of economy to employ gas. If, in fact, a gasworks were to be constructed simply for lighting large spaces, as does occur in some extensive works, the disbursement necessary to establish even a small gasworks would, compared with that necessary to establish the electric light, be a considerable multiple of the latter. Assuming light-power proportional to horse-power expended (although it increases at a greater rate), 100 horse-power would give 150,000 candles light; if this be distributed from three points, the cost of each lamp per hour would not be more than 7s. 6d., or £1 2s. 6d. per hour for the three, each light centre giving an illumination which would enable small print to be read at a distance of a $\frac{1}{4}$ mile from the light. A burner giving the light of 20 candles consumes 6 cubic feet of gas per hour, which may be manufactured at a cost of 2s. per 1,000 cubic feet. This gives 7,500 burners’ light only, and 45,000 cubic feet of gas at a cost of £4 10s. per hour, a ratio of 4 to 1 in favour of electric lighting. Electric lighting, where adopted, has been found to be generally more economical than gas lighting, but the economical ratios differ greatly, and are dependent chiefly upon the price of gas and the motor power employed. For large spaces the cost of electric lighting is about one-fourth, or even one-fifth of that of gas lighting, when steam has been used as a power, and wear and tear are reckoned. With a gas engine as motor, the ratio has only been as 1 to 3, the greatest economy having been with a turbine as motor. At Dieu’s workshops at Davours the cost per hour for gas is 2s. 0 632d. against 1s. 7 2d. for electric lighting. Ducommun finds, taking into account wear and tear and interest, that gas costs 2 25 times more than the electric light, which ratio increases to 7 15 when wear and tear and interest are left out of consideration. At Siemens Brothers’ Telegraph Works the cable shops are imperfectly lighted with 120 gas-burners. Each of these burners consumes 6 cubic feet per hour, at a cost of 3s. 9d. per 1,000 cubic feet. The cost of fixing gas-pipes, including cost of pipes,

burners, cocks, &c., for the 120 burners is £60. Taking interest at 5 per cent., to include wear and tear and renewals, there results for 1,000 hours' consumption per annum—

	£	s.	d.
Interest	9	0	0
Cost of gas consumed	135	0	0
	<hr/>		
	£144	0	0
	<hr/>		

“At the utmost the 120 burners cannot give more than 2,400 candles' light, and naturally but a small percentage of this is reached. Further, when steam or other vapour or fog arises the gas-jets are obscured. The space being subdivided, it is necessary to employ three machines. These three machines, with lamps, conducting wires, mounting, &c., cost £250.*

“Thus the economy is 2 to 1 in favour of electric lighting. But there is the further advantage that the lighting is perfect, and that steam or vapour or fog does not cause inconvenience. If, however, the ratio of light-intensities were adapted to the ratio of efficiency, the advantage would be considerably higher (20 to 1) in favour of electric lighting. It may be laid down, as proved by experiment, that for lighting large spaces not too much subdivided, the advantage is greatly in favour of the electric light; but that when numerous light-centres of small intensity are required, or where the space is much subdivided, the advantage is in favour of gas. This advantage will cease when a practical method of subdividing the electric light has been obtained. In places where opaque objects or screens occur that only throw shadow, but are not of sufficient size to completely block out the light from the space they inclose, reflectors can be utilized to overcome the difficulty of shadows. When the electric light is capable of minute subdivision, it will undoubtedly compete with gas on terms of the highest advantage, since the cost of establishing a gasworks will be many times in excess of that necessary to supply the electric light to a district.

	£	s.	d.
* Interest 15 per cent. upon £250	37	10	0
Carbons, coals, attendance, oils, &c., per 1,000 hours	35	4	0
	<hr/>		
	£72	14	0
	<hr/>		

"The objection that the glare of the electric light is trying to the eyes of the workpeople, has been overcome by inclosing the light in an opaque reflector, the rays being projected on to a screen, or on to the ceiling or roof of the building, whence they are diffused, giving to the space lighted the appearance of illumination by daylight."

PART V.—APPLICATIONS OF THE ELECTRIC LIGHT.

THE comparative cheapness of the electric light and its concentrated power have long ago given rise to the idea of applying it in a large number of special cases, and latterly the hope has been entertained of even using it as a means of public illumination. But without speaking of this application, which, as we shall presently see, has not yet been completely successful, there are a multitude of cases in which this method of illumination can now be employed under favourable conditions; as, for example, in the lighting of large workshops, great retail establishments, works carried on at night, goods stations of railways, drifts in mines, &c. These are cases in which no other system of lighting can yield such adequate and advantageous results. Such are the applications of the electric light to lighthouses, to military operations, to navigation, to submarine work, to projecting on a screen certain scientific experiments, to theatrical effects, to public rejoicings, to maritime signals, &c. These applications we are now about to discuss, and we shall begin with the most general of all, namely, public lighting.

Application to Public Illumination.— Since Davy discovered the wonderful illuminating power of the electric discharge between two carbons, many attempts have been made to apply it to public illumination. These attempts have not yielded very satisfactory results, and this must necessarily have been the case, for besides the cost of this mode of lighting, which was very high, the thing desired was not an intense and concentrated light: such a light is, in fact, insupportable to the eye when near, and it is incapable of illuminating a sufficiently wide area to give a real

advantage over lights dispersed in a number of different points. This truth was established a score of years ago by the experiments in the *Place du Carrousel*, not indeed with the electric light, but with a light equally intense, which formed the centre of a splendidly luminous sphere. It was finally admitted that this single point was far from supplying the same advantages as ordinary gas-jets, which could be placed as required. Now, if we remember that the special characteristic of the electric light is its concentrated power, we may conclude that if this light had to remain subjected to the same conditions under which it existed a few years ago, it would never have been regarded as a mode of public illumination. Nevertheless, the considerable reduction of the cost of this light, and the methods of dividing it under favourable conditions, which have recently been discovered, have changed the aspect of the question. The important experiments undertaken in 1878 by the Jablochkoff Company gave rise to new ideas, which have now been taken up by all civilized countries, and promise to lead to some important results. It is therefore not surprising that the gas companies should have been affected, and their shares depreciated. Nevertheless, we think the depreciation has been unduly exaggerated, for, as we remarked at the beginning, it is difficult to believe that uses will not be found for gas, considering the important purposes to which it can be applied in very many branches of industry.

We have already explained the manner in which the electric light can be divided sufficiently for the requirements of public illumination, by means of induction machines with fixed coils, Jablochkoff candles, the lamps of Lontin, Reynier, Werdermann, &c. We must not, however, suppose that this idea is new. The division of the electric light has long been sought after, and several plans have been proposed, such as those of Wartmann, Quirini, Liai, Deleuil, Ronalds, Lacassagne and Thiers, and Martin de Brettes, which I have described in my *Exposé des applications de l'électricité*,

t. V., p. 550. But these systems, which were founded either on derivations of the current, or on rapid successive permutations of the current through a certain number of different circuits, or on the revolving projection of a beam of light, were destitute of arrangements sufficiently energetic and well contrived to solve the problem. It was not until Lontin, Lodyguine, and Jablochhoff had made their earlier experiments that the possibility of dividing the electric light began to gain some degree of credence. There was still, however, great doubt as to the possibility of illuminating a space of considerable length. It was supposed the loss of electric intensity from the length of the conductors could absorb all the power of the generator, and that sufficient electric energy would not be left to light several lamps. But Jablochhoff's experiments, performed on the whole length of the *Avenue de l'Opéra*, with only one machine for each side of the street, completely removed all doubts on this head, and from that time, as we have already said, the problem of electric lighting has come to the front in every country. We must therefore devote a few lines to these remarkable experiments, which are still carried on at the present moment, and are being extended to other important thoroughfares in Paris.

In the *Avenue de l'Opéra* and the *Place du Théâtre-Français* there are 32 lamp-posts carrying the electric light, 16 on each side. The lamp-posts are the ordinary ones of the city of Paris, supported by circular oaken pedestals 1·5 metres high, and surmounted by lamps like that shown in Fig. 65, page 225. Each lamp holds six candles, and seven wires enter it from the interior of the lamp-post after having passed through a commutator of six contacts placed within the pedestal. The machines which work these different lamps are set up in two cellars under the middle of the street, and therefore the wires are divided into two bundles for each machine; two of these bundles go up the street on each side, and the other two down. The wires are buried in the earth below the pavements, and besides their insulating covering of gutta-percha

and tarred canvas, they are protected by well-fitted drain-pipes. There are openings in front of each lamp-post, and in these are made the connections between the wires of each lamp and those of the circuit. Of course the seven wires are only between the commutator and the candles; everywhere else there are only two for each set of four lamps.

It appears that the two machines require 36 horse-power in order to light 32 lamps on each side of the street, that is, every lamp requires 1·12 H.P.; but it should be noticed that in this estimate the power needed to overcome the resistance of the conductors is included, and that this must be considerable is obvious from the fact that for the most distant conductors it is nearly 1,000 metres of wire.

Jablochkoff asserts that each of the lamps represents from 25 to 30 gas-jets; but F. Leblanc declares that it does not exceed 12 jets, and it is on this estimate that the last contract between the Jablochkoff Company and the city of Paris is based. We must, however, bear in mind that nearly 45 per cent. of the light is absorbed by the enamelled glass globes; so that it is possible that each light represents 50 or 60 Carcel lamps according to Jablochkoff, or 22 to 24 such lamps according to Leblanc. According to the original agreement between the city of Paris and the Jablochkoff Company, the cost to the city was six times that of gas. It is now much reduced, and unless the company is a loser by the new agreement it has entered into with the city of Paris, the cost may be said to be nearly that of gas, for it is only one-fourth as much as under the first agreement.

The debates in the Municipal Council on the renewal of their agreement may illustrate the cost of maintaining this system of lighting. The illumination of the *Avenue de l'Opéra*, together with that of the *Place de l'Opéra*, the *Place du Théâtre Français*, and the façade of the *Corps Législatif*, originally cost 1 franc 25 centimes for each lamp per hour. Now according to Mallet, 68 gas-jets may be had for this sum, and thus electric lighting would be at a disadvantage in the propor-

tion of 1 to 6. But the amount of 1·25 francs was in the last discussion in the Council reduced to 30 centimes, which it seems the Jablochkoff Company have accepted, as the lighting is continued. We think, however, that under these conditions the company must be out of pocket, for according to the calculations of the Reporter to the Municipal Council the cost must amount to 75 centimes.

As the subject is interesting on account of the difficulty of obtaining exact *data*, it may be useful to give a summary of what was said on this subject in the Municipal Council.

According to the Report of Cernesson, the cost of maintenance for each electric lamp per hour may be deduced from the following list of the expenses of lighting 62 lamps for the space of one hour :—

				Fr. c.
Motive power (sundry expenses)	...	...		3'20
Fuel (for the engines)	...	...	...	6'64
Oil for lubrication	...	...	...	1'23
Wages of attendant	...	...	...	3'20
62 candles at 50 centimes each	...	...		31'00
				<hr/>
			Total	...
				<hr/> 45'27 <hr/>

This gives for each candle 0 fr. 75 cent. Yet the Company were content to demand only 0 fr. 60 cent., and wished the Council to enter into an agreement on those terms: the Report did not, however, recommend a compliance with this, but established the principle of paying the Company in proportion to the amount of light supplied.

"Each of the electric lamps," says the Report, "having been supposed to give as much light as 11 gas-jets consuming 140 litres per hour, and costing each about 2½ centimes, the Commission considers that a sum of 30 centimes per lamp per hour should be allotted to the Company. According to the preceding scale the Company would be entitled to only 27 centimes."

As to the Electric Lighting Company's project of undertaking for three years the illumination of the principal

thoroughfares of Paris, the Commission distinctly refused to bind itself in any particular way, but decided that in the present condition of affairs, electricity, as represented by the Jablochkoff candle, could not be considered as having reached such a degree of perfection that it could supersede gas; that, nevertheless, the progress that had been effected was sufficiently real and important to justify a continuance of the experiments on a larger scale. The Commission therefore considers that the *Avenue de l'Opéra* should continue to be lighted as before for one year, beginning on the 15th January, and that the Company might apply its system in two new positions in the city of Paris, viz., the *Place de la Bastille* and one of the wings of the central markets. (See the journal *L'Électricité* of the 5th and 20th January.)

The illumination of the *Avenue de l'Opéra* and of the *Place du Théâtre-Français* allows but one candle to each lamp, and there are in all forty-eight luminous points. On the *Place de l'Opéra* there are only eight lamps, but two candles burn together in each of them; the two triple lamps placed on each side of the façade of the Opera-House have simple candles only. These two lamps are supplied by two *Alliance* machines, but those in the *Place de l'Opéra* are worked by a Gramme dividing machine, and this requires for the electric lighting of this part of Paris the employment of four machines, each using from sixteen to eighteen horse-power. The *Place de la Bastille* and the central market are each lighted by sixteen lamps.

In spite of the fierce hostility with which the gas companies attacked the newspapers in these trials of electric lighting, every civilized country is now turning its attention to this subject. The cities of Stockholm, St. Petersburg, Amsterdam, and San Francisco have already taken steps to establish the electric light. The City of London is at present engaged in realizing this application of electricity, and the Thames Embankment is now lighted in this way. Even America has made repeated attempts to reach an immediate

solution of the problem. Shall we have merely the poor courage to adopt this beautiful application of science only after it has been carried into effect by every other nation, as in the cases of the electric telegraph, railways, &c.? This would be hard, after having made the first experiments.

We have hitherto discussed only the light given by the Jablochkoff candles; but this system is not the only one which may be employed for public illumination, and it is, perhaps, not even the most economical for the light produced. The globes of enamelled glass are, for one thing, a bad arrangement, as they prevent the utilization of the total light, and the Baccarat frosted glass, which allows 70 per cent. of the light to pass instead of 55, have been tried, as we have seen, with much advantage. Again, there is now being tried Pâris's new kind of enamelled glass, which absorbs only 35 per cent. of the light, and Clémandot's globes, formed of concentric spheres of transparent glass, with a packing of glass between them. This arrangement, when tried at shops of the *Louvre*, absorbed, it is said, only 24 per cent. of the light instead of 45. With the Reynier and Wedermann systems applied to the existing lamps, a greater division of the light, and probably a smaller consumption of the carbons, would be obtained, with equal electric intensity. If the carbons were placed within the column of the lamp, which could easily be done in the Wedermann arrangement, they would burn a whole night without requiring attention. Again, with new machines it would be possible to reduce in such a degree the expenditure of motive power that the high price of the electric light, which under the present conditions is the strong point of the partizans of gas, may be sufficiently lowered to compete successfully with gas itself. For lighting on the spot, the problem has, as we have seen, been long ago completely solved; and it is not affirmed that by increasing the section of the conductors, and expending upon them as much as the cost of gas-pipes, public illumination would not be placed under conditions of economy as favourable as if the

light were near the machine. We therefore see no reason why the cost of electric lighting should not come to be lower than that of gas lighting. It is only a question of time, and the important point was to prove that public illumination by electricity was not physically impossible — a matter upon which we now know what opinion to hold.

It has been asserted that the electric light was hurtful to the eye, disagreeable in its effect, and alarming to horses. The experiments of the last six months have not given me any such impression; and if we stand in the evening at the corner of the *Rue de la Paix* and the *Avenue de l'Opéra*, and compare the illumination of the two thoroughfares, especially as regards the houses on either side, we should suppose that one of the streets is dark. Certainly, when the electric lighting of the *Avenue de l'Opéra* is given up, the public will find a vast difference, and will not easily become accustomed to the gas-lamps, which serve only to make the darkness visible; and yet these lamps contain three gas-jets where a little while ago there was only one.

As to the bluish hue of the electric light, it looks cold only because we are accustomed to reddish lights; but if a red tint were required, it would not be difficult to impart it, by introducing certain colouring salts into the composition of the carbons. It is, however, difficult to suppose that this objection is seriously advanced; for it seems to me that a white light, resembling that of the sun and showing colours in their proper hues, is preferable to one which casts a false tint on all objects. Those who find fault with the electric light on this ground must equally object to those beautiful moonlight effects that are so much praised by artists and poets.

In the pamphlet published by the Jablochkoff Company the advantages of electricity for public lighting are thus set forth:—

“Besides the economy of the light it has the following qualities:—

“1°. It does not alter colours, but allows the closest tints to

be distinguished, which would be impossible with gaslight. In every industry where the qualities of objects have to be judged of from their colour, in those where there are sortings or selections according to tints, in assorting stuffs or thread of various shades, the electric light is of unquestioned utility.

"2°. The heat given off by electric lighting is extremely small. It is well known at what trouble and cost a very imperfect ventilation of apartments in which a number of gas-jets are burnt can be obtained.

"3°. In industrial establishments the electric light supplies a general illumination, which facilitates superintendence at the same time that it simplifies all work of transport, management, &c., &c. It enables, therefore, the number of workmen employed in night shifts to be diminished, and consequently the extent of the premises in which the work is carried on to be reduced. There is thus, together with less cost, an economy of labour and an economy of the prime cost of the establishment.

"4°. It removes the danger of using gas, which results either from negligence or from an escape from the pipes, as when the turning of a tap is forgotten or the pipes are fused in a fire otherwise originating.

"Nothing of this kind happens when the electric light is used. Instead of the fusible lead-piping, from which the gas can so readily be allowed to escape, and which can so easily be maliciously injured, the electric communication is by a cord or copper wire covered with an insulating substance. If the circuit were cut, which could only happen intentionally, the reverse would take place from what occurs in the case of gas, for the fluid would no longer flow, and the light would be extinguished. So that, while in the one case the gas from a leakage very easily occasioned, either by accident or by malice, spreads rapidly and forms with the air a mixture that a spark would cause to explode; in the other case, if the circuit is interrupted there is merely a simple extinction of the lights.

"Fires may also be occasioned by the direct action of the gas-jets on combustible materials. Now, an electric lamp having a flame of scarcely any size takes the place of a great number of gas-jets, and the chances of a fire are proportionately reduced. It is, moreover, important to observe that as the combustion of gas gives off much heat, the inflammation of combustible mate-

rials is facilitated by the high temperature of places lighted by gas.

“The electric light, on the contrary, gives off extremely little heat, since a lamp yielding a light equal to that of several hundred stearine candles does not give more heat than a single candle.

“5°. All the lamps supplied by the same dynamo-electric machine are lighted up instantaneously.”

When only a portion of the space has to be lighted in a given direction, and under an angle not exceeding 180 degrees, the diffusion projectors invented by J. Van Malderen may be used with advantage. These consist of a kind of parabolic mirror, of which the electric light occupies the centre, and with the front part closed at a short distance from the arc by a ground glass which receives the beam of parallel rays sent out by the mirror, spreads them out so that all the space in front is illuminated. It is stated that the intensity of the illumination is greatly increased in this way.

I think it will be interesting here to reproduce a letter by Lontin relating to the divisibility of the electric light, which has lately been so much spoken of, and has been put forward as a new discovery, the anterior labours of Wartmann, Quirini, and others being ignored. The letter was addressed to the journal *L'Électricité*, and appeared in the number for 5th November, 1878:—

“Allow me to remind you that two years ago I took out a patent for photo-electric regulators, which divide perfectly the current supplied to them.

“The *Alliance* electro-magnetic machine which was working in the Exhibition, supplied, it is true, 4 Jablochkoff candles, but this same machine, without any change, has worked 12 of my regulators. Here, I think, we truly have the divisibility of the electric light, a divisibility the more real since each of my regulators gave a luminous intensity of 19 Carcel lamps. This luminous power may, moreover, be yet further reduced, for I have obtained intensities of only 4 Carcels. I think I may conclude from these experiments that the *Alliance* machine, or one of my dynamo-

electric machines suitably arranged for that purpose, can supply 50 regulators.

“The illumination of the Lyons railway station last year was supplied by one of my electric generators yielding 12 currents, each current maintaining 2 or 3 lamps. The new apparatus I am now fitting up will allow of 4 lamps being inserted in each current.

“At the Saint-Lazare station each current supplies 2 or 4 lamps, the intensity of which is regulated according to the requirements of the service.”

Application to the Illumination of Lighthouses.

—We are now no longer in the region of hypotheses, the application of the electric light to lighthouses being a *fait accompli* for more than fifteen years (1864), and I am not aware that any serious accident has interrupted the experiments. Most of the important lighthouses on the coasts of France, Russia, and England are thus lighted; and it is to the bold enterprise of the *Alliance* Company and its intelligent director, Berlioz, that the civilized world owes this beautiful application, which has certainly prevented many maritime disasters. It is true that Berlioz has been energetically assisted in his experiments by the Lighthouse Administration, and among others by Reynard and Degrand, who, after many intelligent experiments, arranged the lighthouses of La Hève on this new system towards the end of 1863. Some time afterwards England imitated us, and employed the electro-magnetic machines of Holmes, which were merely an inferior copy of those of the *Alliance*. Le Roux has published in the *Bulletin de la Société d'Encouragement* a very interesting paper on this kind of application, and we should have had great pleasure in reproducing it here had space permitted, but we shall give merely a summary of it, referring the reader to *tome XIV.* of the *Bulletin de la Société*, p. 762.

At the present time, dynamo-electric machines appear to be preferred, and the *Telegraphic Journal* in the number of

the 1st December, 1877, gives many details of the manner in which the apparatus is fitted up in the lighthouses at Lizard Point. This would be very interesting to describe, but for want of space we shall at present content ourselves with considering the way in which the electric light is arranged at the top of the lighthouses.

The illuminating part of a lighthouse is constructed, as shown in Fig. 68, of a glass lantern formed of a certain number of Fresnel's *lentilles-à-échelons* (lenses in steps), in the centre of which the luminous focus is situated. This lantern is turned by powerful clockwork, and it is the passage of the separating zones between the different lenticular parts that produces those eclipses by which the light of a lighthouse is distinguished from that of an ordinary fire. The smaller the luminous point the more the effect is magnified by the lenses, and in order that the light shall be visible from a great distance it is essential that the luminous focus should be as bright and as small as possible. Now, the electric light solves this double problem, and therefore it appears expressly made for lighthouses. Nevertheless, as the electric light regulators are occasionally liable to extinction, and a prolonged extinction might cause serious disasters, the regulators (generally Serrin's or Siemens') are arranged in duplicate. They slide into the lantern on small rails placed on the surface of a cast-iron table, a stop arrests them when at the focus of the lenses, where they instantly light themselves, and this is one of the great advantages of the electric light, especially with the regulators to which we refer. - The electric communication is established on one hand by means of the cast-iron table, and on the other by a metallic spring which presses against the upper part of the lamp at a convenient point. The substitution of one lamp for another does not require more than two seconds, the one which is withdrawn passing out by one of the railways whilst its substitute enters by the other. The light may also be made to pass instantly from one apparatus to the other by means of a

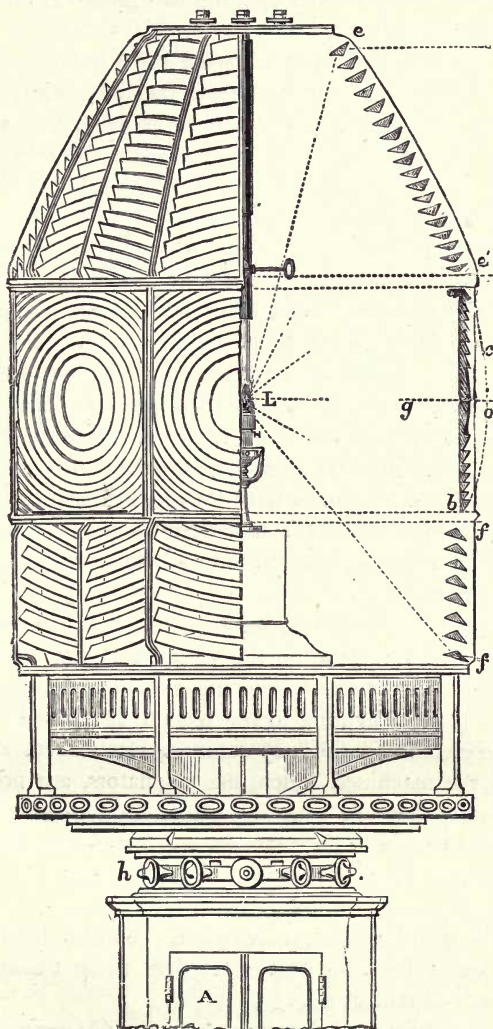


FIG. 68.

commutator, but to centralize the two points of light is a more difficult matter.

The carbons used in lighthouses are 7 millimetres wide and 27 centimetres long, and their rate of consumption is estimated at 5 centimetres per hour at each pole, at least with machines giving alternating currents. In spite of this uniform consumption there is, however, a slight difference, and the upper carbon is consumed a little faster than the lower, in the ratio of 108 to 100. The regulators are therefore very well adjusted, but as it is important that the variation of the luminous point shall be under 8 millimetres, without which the rays will not be sent out to the horizon, it is necessary to carefully attend to this light. In order that the keepers may be able easily to observe the progress of the carbons, an image of them is projected on the wall by means of a lens of short focus, a horizontal line is marked on the wall, and the points must be equally distant from that line. As a deviation of 1 millimetre is represented by a deviation of 22 millimetres on the wall, defects in the adjustment are readily seen.

This apparatus began to work at the lighthouse on the south cape of La Hève on the 26th December, 1863, and after fifteen months of experiments it was decided to apply the same plan of lighting to the second lighthouse. From that time electric lighting was definitely established.

As to the machines, which, like regulators, are provided in duplicate, they are generally placed in the base of the lighthouse tower, with the steam-engines for driving them, and well-insulated cables of a large diameter convey the current to the regulators, as we have already said.

According to Le Roux, it seems that even with the *Alliance* machines of 4 discs, the cost of the light is, on the average, one-seventh of that of oil.

In the natural state of the atmosphere the *Alliance* machines with 4 discs give a light visible at 38 kilometres, and those with 6 discs have a range of 50 kilometres; but it is curious

that in foggy weather the electric light does not carry farther than that of oil lamps.

There are now several electric lighthouses in France, England, Russia, Austria, Sweden, and even in Egypt. Their working is everywhere satisfactory.

Application to the Lighting of Ships.—One of the most important applications of the electric light is for lighting ships in their course so as to avoid fouling, and show the entrances to ports in the night. The earliest attempts were made with the magneto-electric machines of the *Alliance* Company, and although the results were not entirely satisfactory, they were sufficiently successful to show that a solution of the problem would be effected in the immediate future.* The inconveniences for which the plan was blamed may thus be summed up:—The electric light produces round it a whitish cloud, fatiguing to the eye and injurious to observations; the fixed electric light, by its great intensity, obliterates the regulation green and red lights, which is a source of real danger; near the shore, ships might mistake the electric lantern for a lighthouse, and take a false course; finally, the apparatus is cumbersome, and the cost of fitting it up too great for the service it renders.

The greater part of these objections have lately been removed, by raising the luminous lantern to a certain height, by making the light intermittent, and by using the Gramme

* The first attempts of the *Alliance* Company, at that time directed by Berlioz, were made as early as 1855, on board the *Jérôme-Napoléon*, whose commander, M. Georgette Dubuisson, was a strong supporter of the system. They were afterwards repeated on board the *Saint-Laurent*, the *Forfait*, the *d'Estrée*, the *Héroïne*, the *Coligny*, the *France*; and it may be seen by the Reports in *Les Mondes*, tome XVIII., pp. 51, 325, 458, 593, 637; tome XVI., pp. 488, 594; tome XIII., pp. 177, 405, 423; tome VIII., p. 592, that if the naval service in general attached little importance to this application, several distinguished officers fully appreciated its value. At that period, it is true, the electric lighthouses that have given such good results on board the *Amérique* had not been fitted up on ships, but an electric light lantern, very ingeniously arranged, was fixed on the mizzen-mast, and thus removed one of the principal objections that had been made.

machines, which occupy a small space and are not costly. It was on board the transatlantic steamer *L'Amérique*, and under the direction of Captain Pouzolz, that this new system was first established; and it appears to have succeeded perfectly.

Fontaine gives the following details on this subject:—

“The lantern is placed in the upper part of a turret ascended by internal steps, so it is not necessary to go on the bridge, for this turret rises above one of the companion-ladders. This arrangement is very advantageous, especially during heavy weather, when the bow is with difficulty accessible from the bridge. The turret was at first 7 metres high, but Pouzolz had it lowered by 2 metres to increase its stability, and to lower the level of the luminous beam; so that this turret is now 5 metres above the bridge. Its diameter is 1 metre, and it is placed in the fore part of the steamer at 15 metres from the stern.

“The lantern properly so called has prismatic glasses; it is able to illuminate an arc of 225° while leaving the steamer almost entirely in shade. The regulator, which is on Serrin's plan, is hung to the *cardan*. A small seat in the upper part of the tower allows the attendant to regulate the lamp. The luminous beam is about 8 diameters wide.

“The Gramme machine which supplies the luminous arc has a power of 200 Carcel lamps, and is driven by a motor on the Brotherhood system, which reduces the space occupied by the two to 1.20 metres by 0.60. These two machines are placed on a false floor in the engine-room, 40 metres from the lantern.

“All the wires pass through the captain's cabin, who has under his control commutators by which he can at will turn the light on or off in each of the two lamps without stopping the Gramme machine.

“The novelty of the arrangements on *L'Amérique* consists in the automatic intermittance of the light in the lantern. This intermittance is given by a very simple commutator attached to the end of the axle of the Gramme machine, which has the effect of alternately sending the current into the lamp, and into a closed metallic bundle of the same resistance as the voltaic arc, which bundle is heated and cooled alternately. This arrangement was adopted in order to keep the Gramme machine, which makes

850 revolutions per minute under always the same conditions as regards the external circuit. According to Pouzolz's calculations, the best relation between the eclipses and appearances of the light would be a light of 20 seconds and an eclipse of 100 seconds.

"The height of the luminous focus is 10 metres above the water, and the possible range of the light, in consequence of the depression of the horizon, is 10 marine miles (18,520 metres) for an observer with his eye at 6 metres above the water.

"In order to light up the topsails and the gallant-sails while the low sails are left in obscurity, Pouzolz had made a frustum of a cone in tin-plate, and placed it in the movable lamp, with the large opening outwards. In this way the *Amérique* was visible at a great distance from ships and signal-stations when the captain allowed the electric light to continue in action during the whole night."

It will be seen by this description that all the objections offered to the use of the electric light on ship-board have been removed by this new arrangement, and Pouzolz answers those which have been made to the use of an intermittent light by stating that the light produced by short flashes has never incommoded the sight of any officer of the watch or look-out man at the cathead, and that the brilliancy of the green and red side-lights is not at all diminished by the use of the lighthouse in front.

Since the dreadful collisions which have taken place within the last four years, there is now more inclination to resort to the electric light for ships; and we see that, according to Fontaine's book, in 1877, a certain number of Gramme machines have been set up on board several French, Danish, Russian, English, and Spanish ships of war, among which we may mention the *Livadia* and the *Peter the Great* of the Russian navy, the *Richelieu* and the *Suffren* of the French navy, and the *Rumancia* and the *Victoria* of the Spanish navy. It remains to describe the projecting apparatus, which, on account of the small space over which the light is to be thrown, is different from the lenticular apparatus of

lighthouses. This apparatus is not essentially different from that which was put up on board of the *Jérôme Napoléon*. This

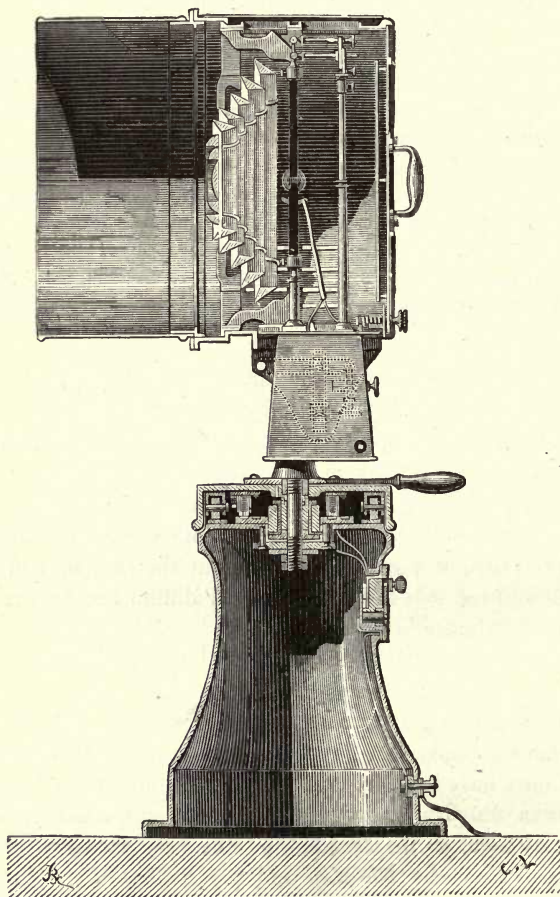


FIG. 69.

consisted of a parabolic reflector, in the focus of which was the voltaic arc produced by a Serrin regulator. This reflector,

a little prolonged in front, was closed by a Fresnel lens, in order to transform the divergent beam into a parallel one. Finally, behind the regulator and the reflector was a small spherical reflector. The whole was mounted in a chamber movable on a pivot which, by a lever and rotating platform, permitted the beam to be sent in any direction. Further, a marine telescope fitted to the apparatus enabled the points of the horizon lighted by the beam to be observed. By placing in front of this beam coloured glasses, the light could be coloured green or red, and thus made suitable for marine signalling.

In Sautter and Lemonnier's projector, represented in Fig. 69, the spherical and parabolic reflectors do not exist, and the whole consists of a

Fresnel lens composed of 3 droptic and 6 catadropic elements. This lens is enclosed in a wide cylindrical tube, which, being supported on a pivot with the whole electrical arrangement, can be turned in any desired direction.

In Siemens' projector, represented in Fig. 70, the parabolic reflector is placed behind the lamp; and the latter is

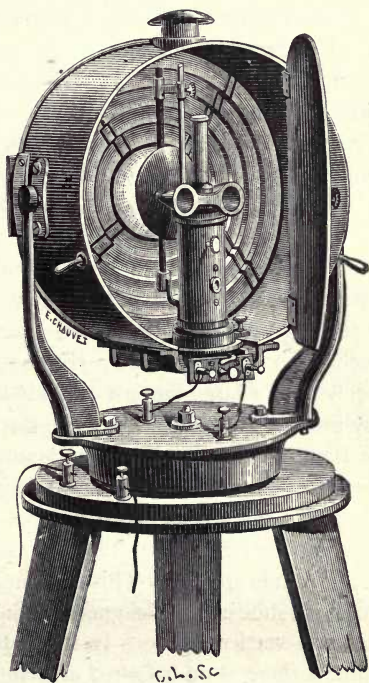


FIG. 70.

also provided with two lenticular arrangements for projecting the image of the carbons on a screen, thus facilitating their adjustment.

Application to Nautical Signals at long range.—

Nocturnal signals exchanged between the various ships of a squadron are often inefficient on account of the feebleness of the light, and it would be desirable to make them clearer and visible at a greater distance. To accomplish this, De Mersanne arranged a particular system of regulator, which could not only be controlled at a distance, but was also regulated without requiring the presence of an attendant near the instrument.

This regulator has its carbon-holders mounted on two vertical rods provided with a screw movement, and capable of turning round on their own axes by an electro-magnetic mechanism controlled by a commutator. The apparatus is enclosed in a large lantern provided in its central part with a cylindrical system of "lenses-in-steps," at the focus of which the luminous arc is placed, and which is so arranged as to direct the light according to the height which the beam has to reach. Now it is in order to always keep the luminous point in the right place that the above-mentioned electro-mechanism is applied. This is composed of two straight and two horse-shoe electro-magnets, arranged in two perpendicular lines in a vertical plane. In the centre of these four electro-magnets there is on a forked armature a lever provided with a steel tooth, which passes between two parallel ratchets inversely disposed to the lower end of the two rods of the carbon-holders. When no current is passing in the electro-magnets the tooth is exactly between the two ratchet-wheels; but if, by means of the commutator, the current is passed through one of the straight electro-magnets—the upper one, for example—the lever already mentioned is raised, and the tooth at the end enters between two teeth of the upper ratchet-wheels, without, however, producing any effect; and

it is only when the current is made to pass through the right electro-magnet that the latter causes the lever to turn, and pushes the tooth by one notch. The screw rod of the regulator then turns, by an amount proportionate to the escape-ment of this tooth, and lowers the corresponding carbon-holder. If now the lower straight electro-magnet be excited, the tooth of the lever engages the lower ratchet-wheel of the rod, and when the current is sent through the left electro-magnet the rod in question turns by the space of a tooth of the ratchet-wheel, but in the direction opposite to the former movement; and this causes the carbon to be raised that before was lowered. As the other carbon is capable of being similarly acted upon in the same way, the luminous point can thus be placed at any desired elevation, at whatever distance the operator may be from the regulator; and he can separately or simultaneously move both carbons as occasion requires.

As to the signals, there are two methods of proceeding. Either the light of the signalling apparatus may be extinguished by a commutator, or the lights may be hid by a screen electrically made to descend in front of the arcs. In the latter case the apparatus are fitted up with a special system of electro-magnets, by which the movement is easily effected. De Mersanne has fitted up several patterns, which may be applied to any other kind of regulator; the problem is not one of any difficulty.

The signalling apparatus just described has been made to work by hand; but the regulation of the light may obviously be automatically produced in a very simple way, by causing a mechanism connected with the light-producing current to act on the commutator already mentioned.

One small detail in the construction of the commutator is of some importance. It is a platinum wire which glows when the lamp itself is lighted, and is extinguished with the latter. The person sending the signals is therefore aware, although he may not see the lamp, when this latter is lighted.

Application to the Arts of War.—The extreme intensity of the electric light, and the ease with which it can at will be made to instantly appear and disappear at a distance, render it capable of important applications in military operations, either for signals, or as a means of illuminating at night a distant point to be observed, or to light up the work of the assailants in sieges. Martin de Brettes published, twenty years ago, an interesting paper on this subject, and this we have reproduced in the second edition of our *Exposé des applications de l'Électricité*, tome III., page 258. We have here space for only a few extracts :

“Signals in the field or at a siege,” says Martin de Brettes, “are chiefly intended for the transmission of orders or urgent despatches. It is therefore clear that the best system of luminous signals is that in which the light is most simply produced, is seen from the greatest distance, and has the greatest regularity in the appearance of the lights combined to produce the signs required in a telegraphic correspondence.

“As to the property possessed by the electric light of being seen at a considerable distance, its superiority for a good system of signals cannot be disputed. Nevertheless, rockets may in general, under ordinary circumstances, be advantageously employed on account of their simplicity, the ease with which they can be carried about and used. But when a powerful permanent luminous signal is required, the electric light will be of great help, and may prevent the use of a captive balloon in the field.

“Again, circumstances occur in war in which an illumination of a longer or shorter duration is required ; for instance :

“To reconnoitre a fortification, the besieger requires a momentary light sufficient for his purpose, and not so prolonged as to attract the attention of the besieged.

“To direct the fire of a battery on a given point, that point must be lighted up long enough to allow a good aim to be taken.

“In order not to be taken by surprise by the opening of trenches, the besieged should continuously light up the ground where that operation is likely to be executed.

“The lighting up of a battle-field or of a breach at the time of the assault, requires also an illumination of an indefinite duration.

"Thus there may be required in war, either a momentary illumination, or one prolonged for perhaps the whole night. We have already seen that these two illuminations can be readily produced at will by the electric light, by closing or interrupting the voltaic circuit."

Martin afterwards explains the conditions for applying the electric light so as to obtain these results. At the time when his paper was written, however, the light could not be produced by electro-magnetic machines, and it would have been necessary to work with the cumbersome materials of a battery, which made the problem one of much greater difficulty. Now, thanks to the small dimensions of the magneto-electric machines, very considerable luminous intensities may be obtained, and this kind of application of the light becomes an easy matter. The magneto-electric—or, best of all for this purpose, the Gramme—machine, may be mounted to a portable engine, which can be as easily moved about to any required position as the cannons. The system used in France is driven by a Brotherhood three-cylinder machine. The electro-magnets of the Gramme machine are thin, flat, and very wide; the bobbin has two current collectors, and a commutator mounted on the armatures allows the machine to be joined up for tension or for quantity. This plan, as shown in Fig. 71, has been adopted by France, Russia, and Norway.

According to Fontaine, it was found, by experiments made at Mount Valérien with a machine thus arranged, that an observer, placed beside the apparatus, is able to see objects 6,600 metres distant, and to distinguish clearly details of construction at a distance of 5,200 metres. To obtain these results, the Gramme machine must have a power of 2,500 lamps, and the projector must concentrate the light by reflection and refraction, as in those projectors we have described for lighting ships at sea.

When the electro-magnets of the machine are joined up for quantity, it turns with a speed of 600 revolutions per

minute, and expends 4 H.-P. ; the light produced varies from 1,000 to 2,000 lamps. In the second case it makes 1,200 turns, employs 8 H.-P., and gives light equal to from 2,000 to 2,500 lamps. When the weather is clear, the machine is joined up for quantity, and the expenditure of steam is then

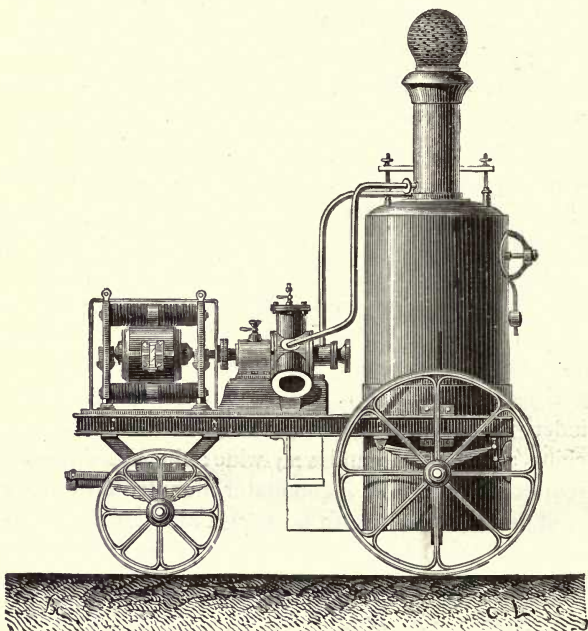


FIG. 71.

small, the working easy, and the carbons are consumed slowly. When the weather is foggy and thick, the machine is arranged for tension, the expenditure of steam increases, the working requires rather more care, and the carbons are consumed quickly. With the Brotherhood motor the change of power is effected instantaneously.

For war signalling, Gramme has fitted up a small machine which can be worked by a man's arm. This machine,

worked by four men, gives a light equal to 50 Carcel lamps. The French Government has lately had it tried.

Experiments with machines arranged in nearly the same way were made in Berlin in 1875. The light produced was intense enough at a mile's distance to allow ordinary writing to be read. When a mirror placed in front of the regulator was inclined so as to reflect the rays upwards, a luminous track was thrown upon the clouds, and from a distance appeared like the tail of a comet, in which the signals made before the mirror showed themselves.

Mangin's projector is the one adopted in France for military operations, and it is in arrangement somewhat similar to that of Siemens', which we have shown in Fig. 70. It is mounted on a low light truck, by which it can easily be taken wherever required. This apparatus, described in detail in the *Mémoirel de l'officier du génie* (Engineer Officer's notebook), is composed essentially of a concavo-convex glass mirror with spherical surfaces of different radii. The convex face is covered with silver, and reflects. This mirror, 90 centimetres in diameter, has the property of being free from spherical aberration, notwithstanding its diameter and its focal length being nearly equal.

Between the mirror and the luminous arc is a concavo-convex lens with its concavity towards the light. Its use is to collect upon the mirror a greater number of the rays, and thus increase the amplitude of the field of illumination.

The beam leaving the apparatus when the lamp is at the focus of the lens is exactly bounded by a circumference almost free from penumbra, and without other divergence than that due to the dimensions of the source of light, which divergence is about $2\frac{1}{2}$ degrees. The light is uniformly distributed over the whole surface.

This apparatus also possesses the property of being made at will, either to light up a considerable space or to concentrate its intensity on one point, and this renders it extremely suitable for certain military operations. A simple displace-

ment of the luminous point produced by a screw effects the change.

In some other experiments made with these apparatus at Toulon and at Cherbourg an unexpected fact was established, namely, that when the concentrated beam is projected upon a ship, the pilot has much difficulty to enter a port. This is a new means of defence.

It has been proposed to send signals from captive balloons. In this case the signal regulator of De Mersanne may be advantageously employed.

Lighting of Railway Trains.—The intense brilliance of the electric light, and the easy method of throwing it in any direction, have suggested in its employment for lighting railway trains running at night, and for announcing them at a greater distance were it only by the illumination of the sky at the place they are passing. Experiments made on the *Chemin de fer du Nord* have been perfectly successful, and seem to indicate that this plan of lighting will one day become general. In the meanwhile Girouard has invented the following system.

The electric generator, or Gramme machine, is fitted up on the tender, and is driven by a toothed wheel moved by an independent piston fixed on the lower part of the frame. One of Watt's governors controls the admission of the steam. A copper tube connected with a cock fixed on the engine is coupled to a pipe leading to the slide valve of the motor cylinder. In order to protect the magneto-electric apparatus from rain and dust, it is enclosed in a wooden casing, and only the cylinder remains outside. It will easily be seen that this arrangement is very solid, although independent of the engine. Its parts can be attended to by the person who usually cleans the engine.

In front of the locomotive there is firmly fixed a lantern containing an electric lamp provided with a powerful reflector, and in front of the lantern is placed, at an angle of

45 degrees, a semi-transparent platinized plate of glass. This glass is mounted in a frame so arranged that it can be turned a little to the right or left, while still inclined at the same angle. Further, a frame containing three coloured glasses, red, white, and green, is placed in front of the reflector, and serves at the same time to protect the lantern from wind and rain.

A jointed rod proceeds from the frame of the inclined glass, and another from the frame carrying the coloured glasses, and these rods are connected with two small levers within reach of the engine-driver. The lamp is connected with the magneto-electric machine by two cables, and when the current passes in the lamp the luminous rays are thrown forward by the reflector, but, as the glass is slightly platinized, only a portion of the beam proceeds straight forwards, whilst the other is projected upwards towards the sky in the form of a cone. By means of the first lever this cone can be turned obliquely either to the right or to the left, while the forward illumination still continues, and by means of the second lever the rays can be coloured either red or green. Now, by giving a certain meaning to each combination, a considerable number of signals may be formed. Besides this, although a train may be passing through a deep cutting or be hidden from sight by curves and inclines, or although the direct view of it may be intercepted by bridges or other objects, the beam projected vertically indicates its position at a great distance.

Application of the Electric Light to the Lighting of the Drifts in Mines, &c.—Several men of science, and among the rest De la Rive, Boussingault, and Louyet, have laid claim to having thrown out the first suggestion of the use of the electric light in mines. The idea originated, as seems to me to have been proved, with Louyet; but the application of it was certainly not made until 1845 by Boussingault.

Everybody knows of the dangers miners are exposed to when gas, issuing from the beds of coal, comes into contact with the flame of a lamp. A dreadful explosion takes place, and fires the whole drift. These sad accidents are called explosions of *fire-damp*. Now as the electric light is independent of a supply of air, for it can be produced in a vacuum, the danger of fire-damp will obviously be avoided, by enclosing each lamp in hermetically-sealed globes, placed in the drifts where the miners are working. It will, however, be necessary to exhaust these globes, lest the dilation by heat of the enclosed air should break them. There is then not the least danger to be feared, for the luminous points are thus completely separated from the external air.

In order to avoid the considerable cost of setting up the electric light, Dumas and Benoit conceived the idea of substituting the light of the inductive spark in a vacuum; they therefore arranged the vacuum tube spirally, and placed it in an outer tube, provided with copper fittings for suspending. The exhaustion is made on Morren's gas, in order to obtain a fine white light. I have spoken at length about this kind of illuminating tubes in my account of Ruhmkorff's induction apparatus (5th edition), and to this I refer the reader.

The electric light produced by the *Alliance* machines was successfully used in 1863 by Bazin for lighting the slate quarries of Angers. A machine with 4 discs was capable of lighting a gallery 60 metres long, by 50 metres wide and 40 metres high. The machine was near the opening of the shaft, and the electric current was transmitted by wires 150 metres long. In spite of the diminution of intensity occasioned by this great length of wire, the illumination proved so satisfactory that the workmen expressed their delight by loud applause. These advantageous results were confirmed on several different occasions, and it was found that the effective labour of the workmen was increased by a fifth or a sixth—a net advantage of 15 or 20 per cent. to add to the comfort of the workmen, which it was desirable to secure

even at a high cost. There were, however, only two points of light. (See *Les Mondes*, tome I., page 691, and tome II., pp. 221 and 278).

The electric lighting of the slate quarries at Angers has lately been provided for in a permanent manner by Lorain. For this purpose a Gramme machine of the pattern described on page 75, and two Serrin regulators, have been used. The large subterranean gallery thus lighted up is no less than 100 metres in length, with a width varying from 15 to 50 metres, and a height of 60 metres. The whole of it—walls, vaulted roof, and floor—is black, yet in spite of the absence of reflection from its surfaces, it is illuminated almost as well as it would be in broad daylight under a clear sky, and with great satisfaction to the workmen and advantage to the Company.

A speed of 800 turns per minute would appear to be sufficient for obtaining a splendid light with the Gramme used, if the regulator had been placed near it; but on account of the depth of the quarry the regulator was about 350 metres from the source of electricity. In order to obtain a good light and a regular working of the apparatus, it was requisite to give the machines a mean and nearly constant velocity of 1,135 revolutions per minute. Conducting wires of a greater diameter are about to be used, and this will allow of such a reduction of the velocity that the electro magnets will not become heated beyond 50°.

The machines have been running simultaneously and continuously day and night since they were put up, eight months ago. With regard to duration and continuity, this experiment is the most conclusive that has hitherto been made with the Gramme machine, which has victoriously stood this severe test. (See the journal *La Lumière électrique* for 15th May, 1879.)

The employment of the electric light for the illumination of works carried on at night was one of the first useful applications of this method of lighting, and, dating from the works

of the *Pont Notre-Dame*, where it was brought into use for the first time, it has always been employed whenever any important work had to be expeditiously performed. It has, for instance, been made use of in the works for the *Docks Napoléon*, in the rebuilding of the *Louvre*, &c., &c. In such applications the lantern is commonly set up at the top of a wooden post, and is furnished with a reflector for throwing the light downwards. It has also been proposed to apply the electric light in field labours in order to expedite harvest operations. Albaret, the head of a great firm of agricultural implement manufacturers at Liancourt, has lately made at Mornant and at Petit-Bourg, experiments that have proved successful. The apparatus (described in the journal *L'Électricité* of the 5th Sept., 1878) is composed of (1°) a portable steam-engine; (2°) a dynamo-electric machine of some kind or other; (3°) a post made of iron bars, serving to carry the lantern and the lamp, and fitted to the portable engine. The engine may, if it has sufficient power, be utilized to drive a thrashing machine. A windlass in front of the chimney enables the post to be raised or lowered.

Application to Lighting Railway Stations, Workshops, &c.—The electric lighting of large workshops and railway stations is now *un fait accompli*. Following Hermann-Lachapelle, who was one of the first to enter upon this course, a multitude of other manufacturers now use it with very great satisfaction. Fontaine's book tells us that Gramme machines now illuminate the establishments of Ducommun, at Mulhouse; of Sautter and Lemonnier, at Paris; of Menier, at Grenelle, Noisiel, and Roye; the spinning-mills of Dieu-Obry, at Daours; of Ricard *fils*, at Mauresa (Spain); of Buxeda, at Sabadell (Spain); of David, Trouillet, and Adhemar, at Épinal; of Bourcard (Doubs); of Horrocks and Miller, at Preston; the weaving-shops of Grégoire, at Crève-Cœur-le-Grand; of Manchon, at Rouen; of Brindle, at Preston; of Mottet and Baillard, at Rouen; of Isaac Holden,

at Rheims; the workshops of Coron and Vignat, at Saint-Étienne; of Maës, at Clichy; of Descat-Leleu, at Lille; of Pulher and Sons, at Pesth; of Carel, at Ghent; the yards of Jeanne Deslandes, at Havre; the workshops of Mignon, Ronart, and Delinières at Montluçon; the quay of the canal between the Marne and the Rhine, at Sermaize; the goods station at La Chapelle, Paris; and also the different places undertaken by the Jablochkoff Company mentioned in pages 228-9.* The result has everywhere been satisfactory. Fontaine's work gives details on the fitting up of these systems of lighting. We shall here merely describe that of the station of the *Chemin du fer du Nord*, on account of the ingenious method by which a light is obtained not fatiguing to the eye, and capable of illuminating the various parts of the hall by nearly perpendicular rays, thus obviating the shadows thrown by packages, and throwing over them a flood of light like that of the torrid zone.

This method consists in arranging round the regulators, which are hung up at various points of the halls, a kind of reflector partly formed by the support of the lamp and partly by a sort of inverted ground-glass funnel, so placed that the luminous arc cannot be seen directly from any part of the hall. The light thus partially stopped is reflected towards the ceiling, as well as that which proceeds from the upper part of the arc; and as the ceiling is painted white, it is capable of forming in its turn an immense reflector, which sends down the luminous rays almost vertically, and thus

* Besides these establishments, Fontaine mentioned, in the beginning of 1877, a number of other workshops lighted in this way. Among the rest were the cannon foundry at Bourges; the workshops of Cail, those of the Mediterranean Iron Works Co. at Havre, those of Crespin and Marteau at Paris, of Beaudet at Argenteuil, Thomas and Powell at Rouen, Ackermann at Stockholm, Avondo at Milan, Quillacq at Anzin; those of Fives-Lille, of Tarbes, of Barcelona; the Midi Stations at Brussels; the workshops at Fourchambault; the foundries of Bessèges and of Fumel; the dye-works of Guaydet at Roubaix, of Hannart at Wasquehal; the weaving shop of Baudot at Bar-le-Duc; the laundry of the Lyons hospitals, &c.

prevents the very dark shadows which would be cast by the packages. By the adoption of this method, it has been found possible to reduce the number of men on the staff for night services, and the number of small articles lost has been much diminished. E. Reynier has improved this system by making the reflecting apparatus and the lantern which causes the regulator much easier to manage. In his arrangement the apparatus is moved like the suspenders in a dining-room. We have not space here to give the details of this interesting arrangement, but we shall, at a later period, publish a more complete description.

The Gramme Company has also fitted up for the shops of the *Louvre* a luminous ceiling, which has proved equally successful. The ceiling is formed in the first place of a large plate of ground unsilvered glass, which constitutes the base of a large hollow pyramid of tin-plate intended to act as the reflector; an electric light regulator suspended and balanced by a counterpoise is placed within this pyramid, so that the reflected rays may be thrown as uniformly as possible on the ground glass. A second reserve regulator can, moreover, be readily substituted for the first one when the carbons have to be renewed.

The light reflecting system, used at the goods station of the *Chemin du fer du Nord*, has been employed at Vienna to illuminate a skating rink 133 metres long. Two Gramme machines and two Serrin lamps, above which were hoisted large reflectors of elliptical curvature, were enough to light up the rink splendidly. This is the most successful of open air applications.

Splendid electrical illuminations have recently been provided at the picture exhibition in the Champs-Élysées at Paris, and at the exhibition of electric light apparatus at the Albert Hall, London. The former have been produced by Jablochhoff candles, the latter with these candles combined with Siemens' lamps. The results, although leaving room for some improvement as regards the steadiness and the

appearance of the illuminated objects, have shown the immense resources this method of lighting places in our hands.

Besides the Châtelet Theatre in Paris, which has for several months been partially lighted by the Jablochkoff system, the Gaiety Theatre in London has been lighted throughout the winter by the electric light, the apparatus employed being Lontin's.

To dismiss the subject of electric illuminations, we may here state the results, as noted in the American newspapers, of the lighting of Cleveland Park, where the Brush system was used. According to these newspapers, this system of lighting must have been more economical than those tried in England and France in the proportion of 4 to 1. It is asserted that this illumination is supplied by twelve Brush lamps of the pattern described on page 178, excited by one of the same inventor's machines not requiring more than 11 H.-P. to drive it, and that each of these lamps has a luminous power of 2,000 candles, or 200 Carcel lamps. These 12 lamps are represented to have advantageously replaced the 100 gas-jets which had hitherto been used, and the amount of light given off is stated to have been about three times that produced by the gas.

We think this account is exaggerated, for if each Brush light represent 200 gas-jets, the 12 should be equal to 2,400 jets. Now, we see that the total illumination is only three times better than the original lighting, which was 100 jets; the Brush illumination would therefore represent only 300 gas-jets, or 25 for each electric lamp.

We must here mention, as important adoptions of the electric light, those recently made at the South Kensington Museum, and at the *Jardin d'Acclimatation* at Bordeaux. There the Werdermann system has been used, and apparently with much success.

Application of the Electric Light to Fishing.—

It has not yet been decided whether the electric light

plunged beneath the surface of the water, attracts fish or drives them away. According to some persons, it would be a means of making miraculous draughts, and Jobard, of Brussels, published in 1865 a very ingenious paper on this application; but we must unfortunately dispel the illusions which were formerly cherished. J. Duboscq has in fact constructed, to the order of an Anglo-French nabob, a large globe lamp for the electric light, with which experiments were made one fine summer evening on the *lac d'Enghien*: the waters were perfectly illuminated, but the fish, instead of coming towards the light, avoided it in alarm; not one was seen, so the apparatus has been useless. This discomfiture is described as above by l'Abbé Moigno; but we observe that his opinion was not very conclusive, for we read in the journal of *Les Mondes*, t. XII., p. 46, t. VI., p. 584, and t. V., p. 374, articles on fishing by the electric light, in which he attaches more importance to the matter. In fact, he quotes an article stating that Fanshawe had been very successful in this way, catching by bait many whittings and mackerel. According to this amateur fisherman, the appearance of the sea during the experiment was splendid; the reflected light carried the greenish-blue colour of the water from the bottom to the summit of every wave. The sails and rigging of the vessel were also illuminated, and it seemed as if it were floating in a sea of gold. The silvery fish darted all around and constantly rose towards the surface of the illuminated water, presenting the appearance of brilliant jewels in a sea of azure and gold. It is true that in another article the author of the *Les Mondes* describes the experiments made at Dunkirk with a submarine lamp excited by currents from an *Alliance* machine, experiments which have left much uncertainty on the action of the light on fishes.

Electric lights have, however, been constructed for fishing, and Gervais has, according to the journal *Les Mondes* of the 30th March, 1865, a rather ingenious one, which is attached to a buoy, and can be let down to any required depth.

Application to Submarine Working.—Since diving-bells and various other apparatus for supporting respiration under water have made it possible to work at the bottom of the sea, several kinds of hydraulic work, and numerous recoveries of sunken vessels have been executed with ease. When the depth of the water which is to be entered is not great, daylight readily penetrates the liquid layer and affords sufficient light to the workers; but at a certain depth the light fails, and the submarine explorations, which must always precede the working, become impossible. No doubt, by fitting a lantern with apparatus for renewing the air, a light may be maintained as men's respiration is maintained; but this necessitates a supplementary pump and special apparatus to prevent the current of air from extinguishing the light. With the electric light the problem is solved in the simplest manner, and the extent of the space illuminated is much greater. The regulator with a globe, which we have already mentioned, may be used, or a special regulator to give the light directly in the water. However, as the light is in this last case much more difficult to control than when it is *vacuo*, the former method is to be preferred.

The experiments made at Dunkirk on fishing by the electric light have allowed the way in which the light behaves under water to be examined, and it has been found that magneto-electric machines, as well as the light they produce, are certainly applicable to submarine working. At a depth of 60 metres the light remained quite steady, and it illuminated a very large surface. The machine, moreover, was placed at more than 100 metres from the regulator. The surface of the glass in the lantern remained perfectly transparent, and the consumption of the carbons was less than in the open air.

Applications to the Projections on a Screen of Optical Experiments, Photographic Transparencies, &c.—There are many physical phenomena which require

to be projected on a screen in order to be visible to a whole audience. There are certain of these (relating to the nature of light itself) which require an extremely intense light to show them. No doubt, with solar light and a heliostat, the problem may be immediately and cheaply solved. But more often than not, the sun is absent when he is required, and we are forced to forego those experiments which not only impart greater interest and attraction to a course of lectures, but which are much better understood and much better remembered when they have been strikingly presented to the eye. The electric light can be most successfully substituted for the sun in this kind of application, and Duboscq's regulators have, as we have seen, been arranged purposely for that object.

The apparatus for projecting the electric light consists of : 1st, an arrangement for steadying the light, so that the consumption of the two carbons does not displace the luminous point ; 2nd, a closed lantern containing the regulator ; 3rd, a plano-convex lens, for making parallel the divergent rays coming from the luminous point ; 4th, of a system of optical apparatus, which we cannot here discuss without departing from the subject of this work.* We shall describe only the lantern, as that is a consequence of the electric regulator.

Duboscq's lantern is formed of a kind of bronzed copper box, which surrounds the upper part of the regulator. To economize space, the column of the regulator is enclosed in a sort of chimney in which the box terminates. To hermetically close the box, small shutters, moved by rackwork, close the top and bottom of the box at the same time that its door is closed, so that the openings made in the instrument for introducing the regulator are completely shut. The inside of the lantern is provided with a reflecting mirror and two supports, on which two other mirrors can be fitted, in order to throw the light on the lenses of a certain apparatus called

* See my account of the method of projecting the principal phenomena of optics by means of Duboscq's apparatus.

the *polyorama*, adapted to the lantern for certain experiments. Finally, in the side of the lantern is a small bull's-eye, with a violet glass, by which the condition of the light is examined. In order easily to regulate the position of the luminous point, which in some experiments must be fixed in the most exact manner, the regulator is placed on a stand which can, by means of two screws, be moved in two rectangular directions (up-and-down and sideways).

The projections may be made at any distance ; only they lose their brightness and clearness where the distance is out of proportion to the intensity of the light : 5 metres is commonly the most suitable distance for the light from a battery of fifty elements. We show in Fig. 72 an experiment of this kind.

The magic lantern gives, with the electric light and Levy's or Favre and Lachenal's transparent photographic views, effects so striking that a spectator would fancy he is transported to the very spot ; and such a perfection in the views is now attained that the objects sometimes seem to stand out in relief, as in the effects of the stereoscope. This method of projection is now much used commercially, and, besides Duboscq's apparatus, which are applicable to every kind of optical experiment, there are those of Molténi, which are exclusively adapted for this kind of application.

Among the projection experiments that have been made by these apparatus, we may particularly mention that of the reading of microscopic despatches forwarded during the siege of Paris by carrier-pigeons ; these despatches, each of which covered less than a square millimetre, were easily read before the multitude of those who were interested in receiving news from the provinces. Fig. 73 represents this application of the electric light.

The electric light has also been used for the photographing of places or objects not otherwise illuminated. In this way Levy has reproduced the pretty fountain under the staircase of the *Grand Opéra*, and certain English and American

artists have succeeded in so truly reproducing the features and details of grottoes and dark caverns, that only by the shadows cast was it possible to distinguish them from places illuminated by daylight. Several photographers have desired to

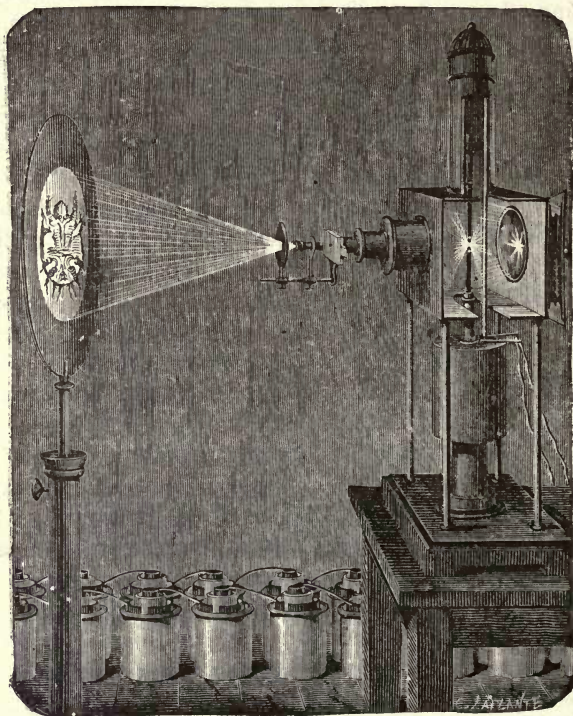


FIG. 72.

use this means for copying and printing, and Pierre Petit and Liebert have even lately fitted up a complete electrical arrangement for taking portraits in this way. We read in the *Scientific Correspondence* of the 14th January, 1879, the following news:—

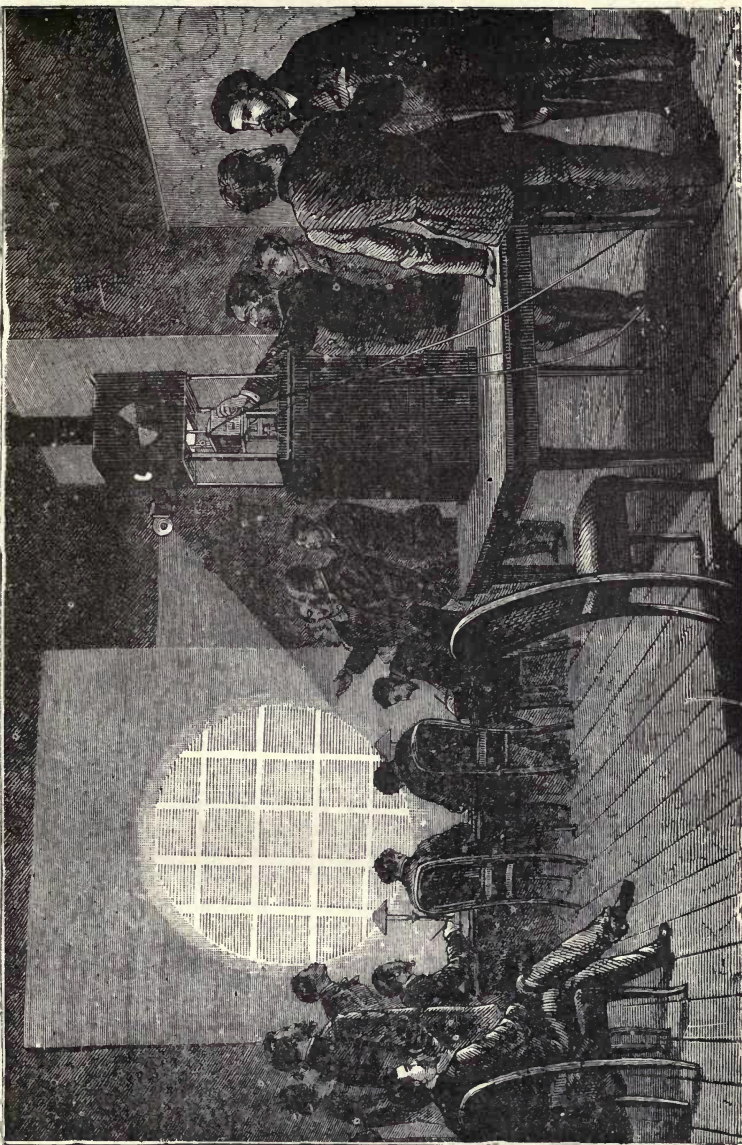


Fig. 73.

"A. Liebert, the well-known distinguished artist, last Saturday invited the press to his artistic and elegant mansion in the *Rue de Londres* to witness photographic experiments by means of the electric light. We use an ill-chosen word in saying experiments, for they were not experiments, but a real and practical application of the electric light to photography. The sun is no longer indispensable; I believe Liebert has even dispensed with his services entirely. By the new system the studio is always ready to receive sitters, at midnight as well as at noon, and the operations are carried on regularly and uninterruptedly.

"Liebert obtains these interesting results by means of a very simple arrangement. A hemisphere of two metres in diameter is hung from the ceiling, so as to present its concavity towards the sitter. This hemisphere carries two electric light carbons, of which one is fixed, while the other is made movable by a screw connected with its holder. The carbons are brought together at right angles to each other. It is, in fact, an ordinary regulator, with only the difference that there is no mechanism, the carbons being brought together by hand as required by their consumption. At each posing of the sitter the two carbons must be placed at the proper point. The duration of the sitting is so short that this cannot fail during the interval.

"The novelty and the improvement of the system consist in the circumstance of the light not falling directly upon the sitter. This light is first of all projected upon a screen, which in turn reflects it to the interior of the hemisphere, which is of dazzling whiteness, so that the luminous rays thus dispersed and divided surround the person whose portrait is to be taken. The illumination is splendid; the face is softly lighted, without any hard and exaggerated shadows. The sitter's eyes easily support the brilliancy of this light, and do not suffer from any unpleasant glare.

"A dozen portraits were taken between 11 o'clock and midnight with the greatest ease, and all were perfectly successful, to the great satisfaction of the guests so kindly invited by M. and Mme. Liebert.

"The electric light used for this purpose is produced by a Gramme machine, driven by a gas-engine of 4 horse-power at the rate of 900 turns per minute."

Public Trials of the Electric Light.—According to a claim advanced by Deleuil in the journal *Les Mondes* of the 26th November, 1863, it was his father who made the first experiment on the large scale with the electric light, and that in 1841 at the *Quai Conti, No. 7*. For this purpose he used a Bunsen battery of 100 cells, and produced the light between two carbons in an exhausted globe. Among the scientific men who were present at this experiment was Cagnard de la Tour, who was able to read a label in the crown of his hat at the base of the statue of Henri IV. Another experiment was made in 1842 by Deleuil père, on the *Place de la Concorde*. Nevertheless, it was Archereau who in the first instance most contributed to popularize the electric light, and I shall ever bear in mind that the experiments made by him every evening, either in the *Rue Rougemont* or in the *Boulevard Bonne-Nouvelle*, determined my taste towards electrical science. This excellent pioneer of science I have, therefore, to thank for starting me in the career I have ever since pursued.

Since these first public experiments many interesting trials of the electric light have been made, as at Rio Janeiro on the occasion of the anniversary of the independence of Brazil, frequently at London, and for two months the *Avenue de l'Impératrice* was lighted by means of two Lacassagne and Thiers lamps put up on the *Arc de Triomphe de l'Étoile*. Wonderful experiments were also made at Boston, in 1863, to celebrate the victories of the Federal armies (see the full account of these fêtes in *Les Mondes, tome II*, page 165); at the ball given at Paris in honour of the Emperor of Russia, equally brilliant experiments were made under the direction of Serrin; they have also long been carried on at *Le Carrousel*, at the *Bois de Boulogne*, at the *Lac des Patineurs*, and in a multitude of other cases where people went to see the electric light as they would go to see fireworks. At the present time the novelty of all these effects has worn off, and we are getting so tired of them that they attract only a

limited degree of attention. On the stage, however, this light produces its full effect, and the play of the *Pommes de Terre Malades*, in which it was used on the French stage for the first time, the operas of *Le Prophète*, *Moïse*, *Faust*, and *Hamlet*, and the ballets of *La Filleule des Fées*, *La Source*, &c., have shown what admirable resources this light has placed at the disposal of the scenic artist.

Application of the Electric Light to Theatrical Representations. — The most striking effects that the electric light has produced on the stage have been contrived by Duboscq. For this purpose he has arranged in the new Opera-House a room set apart for the necessary batteries and engines. Without stopping to describe the effect of the rising sun in *Le Prophète*, which everybody at once admired, and which was produced by a mere upward movement of the regulator—a movement skilfully disguised by a number of more or less transparent curtains; without speaking of the application of the voltaic arc for projecting a bright light on certain parts of the stage, in order to make groups or portions of the scenery stand out brilliantly, we may state that the intense rays of the electric light have served to reproduce upon the stage certain physical phenomena in their natural aspect, such as rainbows, flashes of lightning, moonlight, &c. This source of light is the only one which has proved intense enough to produce on the immense stage of the new Opera-House those effects of light and phantasmagoria which the public find so striking.

According to Saint-Edme, from whom we borrow these details, the rainbow was produced at the Opera-House for the first time by Duboscq, in 1860, in the revival of *Moïse*. The occasion of the appearance of the rainbow in the first act of that opera is well known. At first, bands of coloured paper in the curtain, representing the sky of Memphis, were illuminated by large oil-lamps simply. Afterwards came the electric light, but only the method of illumination was

changed, and it was not until many attempts had been made by Duboscq that a real rainbow was obtained, in the following manner :—

“The electric apparatus supplying the arc,” says Saint-Edme, “is placed on a stand of suitable height at 5 metres distance from the curtain, and perpendicularly to the canvas representing the sky. The whole optical apparatus is arranged and fixed in a blackened case, which diffuses no light externally. The first lenses give a beam, which afterwards encounters a screen cut out in the form of a bow. This beam is received by a double convex lens of very short focus, which serves the two purposes of increasing the curvature of the image, and of spreading it out. On leaving this last lens the rays traverse the prism, by which they are dispersed and made to produce the rainbow. The position of the prism is not a matter of indifference ; its angle must be at the top of the incident beam, or otherwise the colours will not be displayed in the order in which they appeared in the rainbow. By this method the rainbow appears luminous even when the stage is fully lighted.

“It is no difficult matter to imitate peals of thunder in the theatre ; the shops supply *tam-tams* and elastic sheet-iron for this purpose ; but it is not so easy to make lightnings flash on the stage with anything like a natural effect. At first the phenomena was imitated by lighting a narrow zigzag cleft in the scene, with red fire from behind. With the progress of scenic art, it was necessary to do something better, and by the aid of science the source of light was found in the voltaic arc, which is identical in origin with the lighting itself. But what further had to be found, was some optical arrangement by which the luminous beam could be emitted and cut off at rapid intervals, while giving the zigzag movement characteristic of lighting. For this purpose Duboscq had recourse to a kind of magic mirror, in front of which the electric light was placed. This mirror was concave, and the luminous arc was situated at its focus. The upper carbon was fixed, but the lower carbon could at any required moment be drawn back, when the light would flash out. This could also be done by electro-magnetic attraction, and as the mirror was held in the hand it was possible, by shaking it and using the commutator, to obtain currents in various direc-

tions, by which the zigzags of flashes of lightning and their instantaneous apparition were imitated."

Very curious effects may also be produced by Colladon's fountain illuminated by the electric light, by reason of the complete illumination of the jets, and various colours they may be made to assume. But the greatest sensation produced by the application of science to the theatre, has been the apparition of spectres on the stage amongst the actors. The reader will recollect the famous apparitions in the piece called *Le Secret de Miss Aurore*, which drew so many people to the *Châtelet* theatre in 1863; and the performances of Robin and Cleverman are not so long past that one cannot recall the deep impressions produced by the spectres they raised and fought with.

The whole secret of this display consisted in a plate of unsilvered glass placed in front of the actors, and inclined at an angle of 45 degrees to the stage. This plate of glass reflected the images of living spectres, strongly illuminated by the electric light, who were placed in an opening below at the front part of the stage. These images were visible on all sides without intercepting the view of the objects, actors, or scenes on the other side of the glass. It was necessary to success, that the position of the persons representing the spectres should be so arranged that their images should appear vertical and seem to stand upon the floor, and also that their movements should accord with those of the actors on the stage; opening and closing the illuminating apparatus by means of a movable screen, would cause the appearance and disappearance of the spectral images.

PART VI.—CONCLUSION.

IF all that has been said in the foregoing work be mentally reviewed, and its logical conclusions be sought for, the question of electric lighting may thus be stated :—

The peculiar character of the electric light resides in its concentrated power, by which an illumination equal to that from two to four thousand Carcel lamps may be given to a single point. This property may be extremely useful for certain purposes, particularly for lighthouses and ships, but it evidently is an inconvenience as regards public illumination, and for a long time methods have been sought by which this brilliancy may be divided between several lights, in order not only to diminish the glare, but to extend the light over a larger space. Unfortunately, the methods which have been tried for effecting this division have solved the problem only at the cost of a great loss of the intensity produced by a single light. But we shall see that by a well-known arrangement it may nevertheless be utilized under sufficiently favourable conditions.

It is certain that if the electric arc gives a light too intense to be directly borne by the eye, it must be moderated by diffusing globes, by which much light is absorbed and simply lost. This is the case with the Jablochkoff candles, the glass enamel globes of which absorb as much as 45 per cent. of the light. But if by any means the light could be so divided that these diffusing globes would be unnecessary, this loss would cease, and it might happen that with a suitable arrangement there would still be some advantage in using this system in spite of even a considerable loss of light compared with that produced by a single arc. In the first place, this mode of lighting does not involve, like others, a great heating of

the surrounding atmosphere ; and in the second place, there would be nothing to fear from the chances of explosions and fires, nor would the decorations of an apartment be spoiled. Besides, the white light does not change the natural hues of the illuminated objects, and this may be a great advantage for drapers' and other shops where the effects of colours have to be considered. Lastly, on account of the diminished risks, assurance companies will evidently be able to lower their rates.

With regard to expense, it may be that electric lighting will prove cheaper than gas, although the trials already made seem to show the contrary ; but we must remember that these trials are not yet perfect, and we see already that since the erection of the Jablochkoff system in the *Avenue de l'Opéra*, the cost of each electric light, which was at first said to be five times that of gas, was lowered by one-half in the estimate given by the company to the city of Paris, and we think this might again be halved so as to bring the cost to only 40 centimes per hour for each light. It may be said, it is true, that the cost of gas for an equivalent light is only 27 centimes ; but let us suppose that the globes, which absorb 45 per cent. of the light produced, stopped only 24 per cent., as Clémendot believes he can guarantee, the cost would fall below that of gas. These data, it must be understood, are merely approximative, and I quote the above figures only in order to show that it would not be impossible to produce the electric light at a cost within reach of practice. In any case the Company which works the Jablochkoff candles has rendered an immense service by showing the possibility of lighting of public thoroughfares by the electric light, which had before that been doubted. We have to thank the initiative taken by the Company, and the beautiful experiments it instituted, for electric lighting having become a question of the day, and in every country new researches have been prosecuted, which will sooner or later lead to the solution of the problem. Several towns in Europe and

America are about to be illuminated by this system, of which we believe we have not heard the last word.

It is already certain that a more complete study of the division of the light will lead to results more satisfactory than those already known.

In order that some idea may be formed of the improvements within our reach, it will suffice for me to say that, in the investigations hitherto made, the various elements that play an important part in the magnitude of the effect produced have not been sufficiently attended to. Thus, for example, a well-known relation between the resistance of the external circuit and that of the generator can greatly increase the proportion of the useful work. Nor should it be forgotten that the intensity of the light varies in proportion ever so much greater than that of the intensity of the electric current. It is already known that the calorific action produced by the current varies as the square of its intensity, but the resulting light varies in a still higher ratio; for, according to Preece, a platinum wire heated to $2,600^{\circ}$ F. gives forty times as much light as when it is heated to $1,900^{\circ}$ F. This explains why the division of the light is attended by so great a loss; since with each weakening of the current resulting from this division, there is a loss of light which may, under certain conditions, attain the eleventh power of the ratio of the diminution of the current.

All these considerations show that the solution of the lighting problem requires much further investigation before it becomes altogether practical; but we believe that no one of the questions belonging to it is insoluble, and that before long we shall witness at least a partial transformation in public illumination.

NOTES AND APPENDICES.

NOTE A.

ON THE INDUCTIVE ACTIONS IN THE NEW DYNAMO-ELECTRIC MACHINES.

THE inductive actions resulting from the relative movements of the inducing and induced circuits are seldom studied with exactitude, and on that account very inaccurate theories of several recently invented dynamo-electric machines have been put forward. The following series of experiments may serve to fix our ideas on the subject:—

Let us suppose that on a powerful straight magnet are wound several spires of an insulated wire, the ends of which are connected with a distant galvanometer, and let the coil so formed be capable of taking different positions on the magnet. If this coil is placed at the south pole of the magnet, and a soft iron armature is brought near that pole, a current will be obtained corresponding in duration with a magnetizing current, for it results from the increase of magnetic energy communicated to the bar by the presence of the armature. This current will give a deviation of 12 degrees to the right, and on withdrawing the armature we shall have a second deviation of 12 degrees to the left. Therefore, in the following experiments a deviation to the right will represent *inverse* currents, and a deviation to the left, *direct* currents.* Let us now see what will happen from the various

* It should be observed that the direction of the currents due to the increase or diminution of magnetic intensity is always the same, whether

movements given to the coil when it is passed from the poles towards the neutral line of the magnet, and from the neutral line towards the poles. This is what will be observed :—

1°. When the coil is passed from the south pole towards the neutral line, a deviation of 22 degrees to the right will be obtained, and therefore an *inverse* current, or one of magnetization.

2°. On making the reverse movement a new current will be produced, and will cause a deviation of 25 degrees towards the left, and therefore the current will be *direct*.

3°. If, instead of passing the coil from the neutral line towards the south pole, the first movement is continued by bringing the coil from the neutral line towards the north pole, a current will be obtained in the direction opposite to that produced in the first half of the movement, and if the coil is stopped half-way a deviation of 12 degrees to the left will be obtained.

4°. On bringing the coil back from the last position

the currents are evoked at one or the other pole of the magnet, or at both together, and whatever may be the position of the coil on the magnet. But the currents produced will be the more energetic as the action takes place nearer to the coil. Thus, by placing the coil at the centre of the magnet on the neutral line, the current due to the increase of magnetization resulting from the approximation of an iron armature to one or other of the two poles will be inverse and of 2 degrees, and that which will result from the removal of the armature will be direct and of the same intensity. By acting simultaneously on the two poles and developing the armature, these currents will show themselves in the same direction, and will attain an intensity represented by 7 degrees. If the coil is placed at one of the poles, at the south pole for instance, the currents will be of 10 to 12 degrees, when the armature is brought near, or withdrawn from, the south pole; but they will be of only $\frac{1}{2}$ degree when the north pole is acted upon, and but of 9 degrees when the armature acts upon the two poles simultaneously.

On placing the coil near the north pole, half-way between that pole and the neutral line, we shall have an inverse current when the armature approaches the poles; but it will be one of only 5 degrees when the north pole is acted upon, and one of only 2 degrees when the south pole is acted upon. It will become one of 9 degrees when the armature is made to act upon both poles at once, and the effects will of course be reversed when the armature is withdrawn instead of being brought near.

towards the neutral line, a fresh deviation of 10 degrees to the right will be obtained.

It follows from these experiments that the induced currents, caused by the movements of the coil along the magnet, will be the same as if the neutral line represented a *resultant of all the magnetic actions of the bar*. If this resultant were represented by a line through which the whole magnetic current were passing, there would follow from the approach of the movable coil to this line a current which, according to Lenz's law, would be *inverse*; and this is in fact precisely what takes place, since in bringing the coil back from the south pole, or from the north pole towards the neutral line, deviations to the right are obtained. Besides, it must follow from the same law, that on withdrawing the movable coil from that line, *direct* currents should be obtained, and this is found to be the case, since the deviations are to the left.

It will therefore be understood that, in accordance with these considerations, a small coil movable round a magnetized ring, setting out from the neutral line of one of the two semicircular magnets composing the ring, and moving towards the inducer by which the ring is polarized, must give a *direct* current, and this is precisely what is observed in the Gramme machine.

Let us now examine what occurs from the passage of the coil just mentioned, before the inducing pole itself, which I shall suppose to be the south pole of the preceding magnet; but this time, instead of taking the small coil, of which we spoke at first, we shall take a real bobbin of little thickness and capable of sliding along an iron rod, which acts on its magnetic core. In order to know the directions of the currents that we shall observe, we shall begin by examining the direction of the current produced when we bring near the south pole of the magnet the small bobbin, which we shall present by its anterior extremity, that is to say, by the extremity which in the following experiments goes first. Under these conditions we shall obtain a deviation to the right of

25 degrees, and when we withdraw the coil we shall obtain a deviation of 22 degrees to the left. As this experiment is the reproduction of Faraday's well-known one, we perceive that the deviations to the right will represent *inverse* currents, and that the deviations to the left will represent *direct* currents.

Now, if we take the coil in question, and cause it to pass from right to left tangentially before the south pole of the inducer, taking care to produce the movements in two parts, we shall observe :—

1°. That in the first half of the motion a current will be produced causing a galvanometric deviation of 8 degrees to the left, and in the second half another current of 5 degrees in the same direction.

2°. That in effecting the movement in the contrary direction, the current will be produced in the inverse direction.

It may therefore be concluded that the *currents resulting from the tangential movement of a coil before a magnetic pole* are produced under conditions altogether different from those which result from a movement effected in the direction of the axis of the magnet. These two movements are, in fact, produced not only in two perpendicular directions, but also under different conditions with regard to the manner in which the induction is produced in the various parts of the spiral. In the case of the tangential movement, the induction takes place only on one half of the circumference of the spires, and it acts from the two sides on a different end of the coil. It is not thus in the other case; the relative positions of the different parts of the coil remain in the same condition as regards the inducing pole, and it is only the position of the resultant that varies with regard to the direction of the motion.

It remains to find what occurs when the coil performing the movements just considered is subjected to the action of a magnetic core, influenced by the inducer, and in this case it suffices to cause the coil to pass along the iron rod of

which we have spoken, while exposing the latter to the action of the inducing pole. On proceeding thus the following effects are observed :—

1°. At the first moment, when the inducing pole is being brought near the iron rod, but at a distance sufficient to allow the coil to pass between it and this pole, there is produced in the coil, placed on one side, an induced current which results from the magnetization of the rod, and gives a deviation of 39 degrees to the right. The deviations on this side correspond then with *inverse* currents.

2°. When the coil, placed as in the first series of experiments, is moved from right to left, it produces, from the moment it comes near the inducing pole, a current of 22 degrees to the left, which is, therefore, a *direct* current, and by continuing the movement beyond the inducing pole a new current is obtained in the same direction of 30 degrees to the left.

The effects produced by the passage of the coil before the inducer are therefore in the same direction with or without an iron rod, but are much more energetic with the iron rod.*

* The effects produced in this experiment should be carefully noted, for they prove that the magnetic actions are not so simple as is generally supposed. In fact, the results which we have just pointed out cannot be established unless the movable coil is placed on the part of the induced iron rod, intermediate between the inducing pole and its free extremities. Beyond this intermediate part the currents produced are in the opposite direction, which proves that in this case the iron rod has become a true magnet regularly constituted. Of course, if the rod is exposed to the inducing pole at one of its extremities, the magnet has only two poles and one neutral line; but if it is exposed to this inducer at its centre, it forms a magnet with a *consequent point*, and has therefore two neutral lines. If, however, the iron rod, instead of being at a distance from the inducing pole, is in contact with it, the effects are quite different. The currents produced by the movement of the coil towards the magnet are always inverse, and those which result from its withdrawal are direct. This shows that the resultant of the magnetic forces is then concentrated at the inducing pole, which plays the part of a neutral line, as if the two magnetic pieces formed but one. This effect is always produced, on which side soever of the magnetic pole the iron rod is applied. If, however, under these conditions, the rod is separated from the magnet by a magnetically isolating substance, the effects without being

It may therefore be said that the currents produced in consequence of the displacement of the coils of a Gramme ring, in relation to the two resultants corresponding with the two neutral lines, are in the same direction as those evoked by the passage of the spires of the coils before the inducing pole in each half of the ring.

In order to study the effects resulting from the *polar inversions*, the experiment may be arranged as follows:—on one of the extremities of the iron rod provided with the induction coil mentioned above, a permanent magnet is made to slide perpendicularly to its axis. In this way the rod undergoes successive inversions of its polarities, and it is seen that not only is there produced by this a current more powerful than the magnetization and demagnetization currents which result from the action of the pole of the magnet, but also that this current is not momentary, and appears to increase in energy until the inversion of the poles is complete. The direction of this current varies according to the direction of the movement of the magnetized bar, and if it is compared with that which results from the magnetization or demagnetization of the magnetic core under the influence of one or other of the poles of the magnetized bar, it is observed that it is *exactly of the same direction as the demagnetization current caused by the pole that has first acted*; it is therefore in the same direction as the magnetization current of the second pole; and as, in the movement performed by the magnet, the magnetic core is demagnetized, in order to be again magnetized in the con-

exactly those we have analysed with the tangential movement of the coil, somewhat resemble them, and the difference depends upon the currents, resulting from the movements of the coil with regard to the magnets, being in the direction contrary to those which result from the magnetization of the rod, and giving rise to a rather feeble differential current, which shows that the last action preponderates. On the other hand, the currents produced from the middle of the rod to its free extremity, being no longer opposed by the direct action of the magnet, possess all their energy. (See my paper on this kind of actions in the *Comptes Rendus* for the 24th February, 1879.)

trary way, the two currents which result from these two consecutive actions are in the same direction, and consequently supply a single current during the whole movement of the magnet. Again, the movement in the opposite direction of the magnet, having for its effect at the beginning a demagnetization in the direction opposite to that produced in the first case, the retrograde current resulting from the retrograde movement must be in a direction the reverse of that of the first.

If we now return to the effects produced by our magnet, acting on our coils moving perpendicularly to their axes, it will be understood from the preceding that displacement of the magnetic polarity of the core must immediately be produced by the inducing magnet having for its effect the inversion of the contrary polarity of this core before and behind the points successively influenced, it must follow that the different parts of the core of the coils will successively constitute a series of magnets with inverted poles, analagous to those the effects of which we have already analysed, and which are able to produce those currents in the same direction, whose presence we have proved. These currents will change in direction according as the coils move from right to left, or from left to right. (See my article on the electrical actions in operation in light-producing machines, in the journal *La Lumière Électrique* of the 1st November, 1879.)

NOTE B.

ON THE DUTY OF GRAMME MACHINES ACCORDING TO THE RESISTANCE OF THE EXTERNAL CIRCUIT.

WE reproduce below an interesting paper of Hospitalier's, which shows the importance of the remark made at the conclusion of this work.

Dynamo-electric machines, considered as a source of electricity, cannot, by reason of the numerous conditions of their action, be classed with other electric sources, such as liquid batteries or thermo-electric batteries, and therefore, thanks to the kind co-operation of Robert Gray, the engineer of the *Indiarubber Works Co.*, we undertook at Silvertown, in the month of July, 1879, a series of experiments to establish, apart from all theoretical considerations, the electric elements of dynamo-electric machines placed under certain conditions of action.

Our experiments had reference to Gramme machines of the A pattern, called the workshop pattern (represented on page 75 of this volume.) We must mention that similar experiments had been already made in France by Mascart and Angot (*Journal de Physique*, 1878), and in England by Hopkinson (*Institution of Mechanical Engineers*). The former were undertaken more particularly from a theoretical point of view, from which we cannot here regard them; the latter relates to Siemens' machines, and it is a similar investigation that we desire to have made in France on the machines which are here most in use.

Dynamo-electric machines are set up to work at a given speed, which it is convenient to maintain in order to produce from these machines all they can yield without damaging their parts or the solidity of their construction. We suppose, then, that the speed of rotation is constant, and we refer the electric elements to a normal velocity of 1,000 turns per minute. When the register indicates a greater or less velocity it is always easy to reduce it to this standard, for it is found by experiment that, other things being equal, the electromotive force is proportional to the number of revolutions of the machine even for variations reaching to 300 turns a minute.

We were particularly desirous of experimentally explaining the variations of the electric elements of the Gramme machines, by causing the external resistance to vary from 10 ohms to an external resistance of nothing.

Internal Resistance of the Machine.—On testing by the method of Wheatstone's bridge, the resistances of the machine experimented with were found to be :—

	ohms.
Total resistance of the machine before working	1'185
Resistance of the coil when warm, after having been working some time in short circuit	0'75
Resistance of the electro-magnets under the same conditions ...	0'72
Total resistance of the machine when <i>warm</i>	1'47

These figures show that the *internal resistance* of the machine varies within very narrow limits, and that these variations are due to the heating of the wire, the resistance of which increases with the temperature.

Electro-motive Force.—Curve I. of the diagram, given in Fig. 74, shows the variation of the electro-motive force when the external resistance increases. The total resistances are referred to the axis of the abscissæ, on a scale of $\frac{7}{10}$ ths of a centimetre per *ohm*; the electro-motive forces are referred to the ordinates on a scale of $\frac{7}{10}$ ths of a millimetre per *volt*. When the total resistance is more than four times the internal resistance, it will be seen that the electro-motive force is nearly constant and very feeble. This is due to the fact that the induction on the coil is produced only by the residual magnetism of the electro-magnets. Then this electro-motive force increases very rapidly between 6 ohms and 4 ohms of total resistance, and it reaches a value of 107 volts, varying then very little. This is caused by the electro-magnets being magnetized to saturation; the magnetic field remains constant, and as besides the speed of the induced system is constant, the electro-motive force, which is proportional to these two quantities, can vary only by the heating of the wire.

Intensity of the Current.—The intensity of the current, expressed in *webers*, is represented by the curve II. of the diagram on a scale of $\frac{7}{10}$ ths of a millimetre per *weber*.

It will be seen that this intensity, at first very feeble, increases afterwards in a nearly regular manner for total resistances varying between twice and four times the total resistance of the machine. These intensities have been calculated by the formula

$$Q = \frac{E}{R}$$

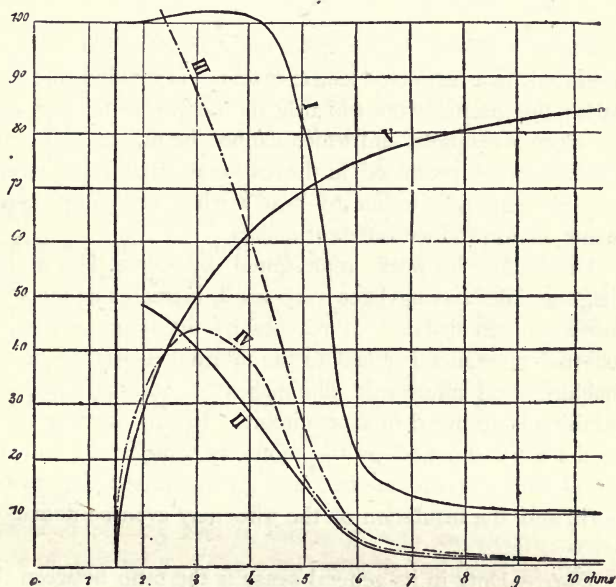


FIG. 74.

in which Q is the intensity in webers, E the electro-motive force in volts, R the total resistance in ohms.

Work transformed into Electricity.—The figures we have found are referred to the unit of time, the second. The value of the work transformed into electricity is expressed by Joule's formula, $w = 10 Q^2 R$, in which Q and R have the same meaning as before, and w is the work in *meg-ergs*. In

order to reduce to French units or kilogrammetres we must know that the kilogrammetre equals 98·1 *meg-ergs*.

Curve III. of the diagram shows that the work transformed into electricity, which is very small when the total resistance exceeds 6 ohms, increases afterwards rapidly and regularly as the resistance diminishes. The scale of curves III. and IV. is $\frac{7}{10}$ ths of a millimetre for 2 kilogrammetres.

Utilizable Work in the External Circuit.—The current produced by a magneto-electric machine is divided into two parts: the internal work which heats the wire of the coil and the electro magnets, and which cannot be utilized, and the available work produced in the external circuit, and which may be employed either to heat a wire, as in our experiments, or to produce different effects.

The utilizable work, represented by curve IV. in the diagram, after having been very small, increases as the total resistance diminishes. It reaches its maximum when the external resistance is equal to the internal resistance of the machine, and afterwards diminishes to nothing when the machine is arranged in short circuit. In this case the whole of the work supplied by the motor is transformed into internal work, the machine becomes greatly heated, the brushes burn, and the insulation of the wire may even be damaged.

Duty.—Duty in its general sense is the ratio between the work expended and the work utilized. If only the work transformed into electricity is taken into account, as we shall do here, by neglecting the passive resistances and the friction of the parts, the duty is the ratio between the total work transformed into electricity (curve III.), and the work utilizable in the external circuit (curve IV). This ratio, always less than I., is represented by curve V. in the diagram. It will be seen that this ratio increases with the resistance, and tends towards I. for an infinite resistance, in which case there is no longer any current. This assertion seems, in

contradiction to that which has often been made, that the duty is maximum when the external resistance is equal to the internal resistance. There is in this an error in the words which must be rectified.

It is not the *duty* that is maximum in this last case, for it is only 50 per cent., but *the utilizable work in the external circuit*. The largest quantity, therefore, of utilizable electricity will be obtained from a given machine by making the external resistance equal to the internal resistance, but the *highest electrical duty* will be obtained by making the external resistance equal to 5 or 6 times the internal resistance. Under these conditions the machine will supply very little electricity, but the greatest part of it will be utilized on the external circuit. In practice, it is preferred to lose on the duty, and to cause the machine to produce the most that it can furnish at its normal velocity, by placing it under the conditions of maximum utilizable work, a maximum which is attained when the external circuit is equal to the internal resistance, certain corrections being made, which, according to the experiments of Jamin, Roger, and Le Roux, must be introduced into the value of the internal resistance.

In one experiment, the machine turning with a velocity of 1,000 revolutions per minute, with an external resistance of 2.7 ohms, or 1.8 times the internal resistance, a current was produced of 25.5 webers intensity, with an electro-motive force of 107 volts. The total work transformed into electricity was 273 kilogrammetres, or 3.64 horse-power; the utilizable work was 179 kilogrammetres, or 2.38 horse-power.

In this case the duty reached 65 per cent. By taking into account friction, passive resistances, &c., the value of which might reach 1 horse-power, the utilizable work is only about 50 per cent. of the work really used up by the machine.

Experiments made under various conditions of resistance on different machines manufactured at Silvertown gave similar results.

Tension and Quantity Machines.—If, on a given dynamo-electric machine, we expend a certain quantity of work w , the expression of this work transformed into electricity may be put into this form:— $w = Q E$. Now this may be done in these machines in two ways.

By making Q very great and E very small, the machine, having then little tension and supplying a large quantity of current, takes the name of a *quantity machine*.

Q may also be made very small and E very great; the machine, having little quantity and a large electro-motive force, takes the name of a *tension machine*.

The former class should work with an external circuit of small resistance; the latter, on the contrary, requires a considerable external resistance to satisfy the relations which should exist between the external and internal circuits in order to obtain the maximum utilizable effect.

In conclusion, we give a table showing the different values assumed by the electric elements of a machine, according as it is constructed to supply a so-called quantity current, or a so-called tension current.

Elements of the working of Gramme machines, determined by experiments made at Silvertown, July, 1879.

Electric Elements.	Quantity Machine.	Tension Machine.
Number of turns per minute	797	967
Internal resistance in ohms	1'20	4'58
External resistance	1'14	4'00
Total resistance of the circuit	2'34	8'58
Intensity of the current in webers... ..	29'67	17'51
Electro-motive force in volts	81'53	158'50
Work expended in kilogrammetres	243	277

It will be seen that, according to this table, for the same quantity of work expended, the electric elements, resistance, intensity, and electro-motive force are notably different.

It is possible to construct intermediate machines by suitably adjusting the lengths and thicknesses of the wire on the coils; but the figures we have just given show within what limits the Gramme machines used for the electric light are comprised.

NOTE C.

THE CRITERIA OF THE ELECTRIC LIGHT.

WE here extract the following passages from a paper by W. H. Preece, which we find in the *Telegraphic Journal* of the 15th February, 1879:—

“Heat and light are identical in character, though different in degree; and whenever solid matter is raised to a very high temperature it becomes luminous. The amount of light is dependent upon the height of this temperature; and it is a very remarkable fact that all solid bodies become self-luminous at the same temperature. This was determined by Daniell to be 980° (F.), by Wedgwood 947° , by Draper 977° ; so that we may approximately assume the temperature at which bodies begin to show a dull light to be $1,000^{\circ}$ (F.) The intensity of light, however, increases in a greater ratio than the temperature. For instance, platinum at $2,600^{\circ}$ (F.) emits forty times more light than at $1,900^{\circ}$. Bodies when raised to incandescence pass through all stages of the spectrum: as the temperature increases so does the refrangibility of the rays of light. Thus, when a body is at a temperature of—

250°	F.,	it may be called	warm.
500°	”	”	hot.
$1,000^{\circ}$	we have the red rays.		
$1,200^{\circ}$	”	”	orange rays.
$1,300^{\circ}$	”	”	yellow rays.
$1,500^{\circ}$	”	”	blue rays.
$1,700^{\circ}$	”	”	indigo rays.
$2,000^{\circ}$	”	”	violet rays.

So that any body raised to a temperature above $2,000^{\circ}$ will give us all the rays of the sun. Inversely, the spectroscope may thus be enabled to tell us the temperature of the different lights, and it is, perhaps, because some lights do not exceed $1,300^{\circ}$ that we lose all those rays beyond the yellow.

“Tyndall has shown that the visible rays of an incandescent wire bear to the invisible rays a much smaller proportion than in the arc, and it is generally assumed that for the same current the arc will give at least $2\frac{1}{2}$ times greater light than an incandescent wire. Tyndall’s figures are as follows :—

				Visible Rays.	Invisible Rays.	
Gas ...	...	...	...	I	to	24
Incandescent wire			...	I	to	23
The arc	...	...	...	I	to	9

“The requirements of a good electric lamp are first, intense brilliancy; secondly, great steadiness; thirdly, duration. The Serrin lamp has the first kind of excellence; all those lamps based on incandescence excel in the second respect; the Wallace Farmer light is the only one that attains the third point. The Rapiéff is perhaps that form which, up to the present, most nearly combines the three requisites, but in reality no lamp has yet been introduced which fulfils all these requirements.

“The objections to the use of the electric light are :—

1°. The deep shadows it throws.

2°. The indifferent carbon that has hitherto been manufactured for the purpose, which leads to unpleasant sounds, to great variation in the intensity of the light, and to waste.

3°. The difficulty in distributing the light itself. It is so intense, and confined to so small a space, that it does not lend itself to distribution like the gas flame, which occupies a considerable space.

4°. The unsteadiness of the light due to variations in the speed of the engine employed in driving the dynamo machine. There is another cause of variation in the electric arc, and that is the variation in the resistance of the arc itself, for it

has been clearly demonstrated by experiments both in America and in England, that the resistance of the arc varies as the resistances in circuit vary. The following table will show this:—

Current in Webers.	Light in Candles.	Resistance of Arc. Ohms.
10	440	2'77
16'5	795	1'25
21'5	900	1'67
30'12	1,230	'54

“The light in the arc varies directly as the current, and not as the square of the current, as generally assumed.

“Now, in the case of light raised by incandescence, the light will increase as the square of the current. It follows that if in the one case—viz., the arc—the light increases as the current only, and in the other case—viz., incandescence—it increases as the square of the current, a point is reached when the light produced by incandescence will equal that produced by the arc. The difficulty in reaching that point is the difficulty of obtaining a conductor with a sufficiently high point of fusion to resist the effect of powerful currents. Iridium is the only metal that is known to do this, and iridium is too scarce and too dear to be used for the purpose.

“The multiplication of the light by Gramme’s machine upon the Thames Embankment must not be taken as the solution of the problem of the subdivision of the light. Theory shows unmistakably that to produce the greatest effect we must have only one machine to produce one light. We know from absolute measurements that such a machine can be made to produce a light of 14,880 candles, and it is possible to produce 1,254 candles per horse-power. But the moment that we attempt to multiply the number of lights in circuit this power diminishes, so that we have on the Embankment lamps giving us a light of scarcely more than 100 candles. The light of the Rapiëff lamp in the *Times* office appears to be about 600 candle-power, and the Wallace light is equal

to 800 candle-power. In these two instances six lights are used in one circuit, but we have not here the subdivision of the light ; we have, on the contrary, the multiplication of the light, produced by the increased speed of the engine due to the insertion of additional lamps. It is, however, easily shown that if in a circuit where the electro-motive force is constant we insert additional lamps, then when these lamps are joined up in one circuit, *i.e.*, in series, the light varies inversely as the square of the number of lamps in circuit, and when joined up, as in the multiple arc, the light diminishes as the cube of the number inserted. Hence the subdivision of the light is an absolute *ignis fatuus*. In the first place no machine has yet been produced which is competent or capable to light over 20 lamps ; secondly, no conductor is known but copper that is capable of conveying the current required to light these lamps, and copper is an expensive material ; thirdly, no electric light has yet been produced combining all the criteria of a good light."

We consider this conclusion somewhat premature, and we must confess that on this point we do not quite agree with the learned English electrician.

NOTE D.

ON A NEW ARRANGEMENT OF THE WERDERMANN LAMP.

The new arrangement of the Werdermann lamp, mentioned on page 209, consists in the addition to the arrangement shown in Fig. 56 of a brake acting on the lateral contact, and put in operation under the influence of the end contact, which is for this purpose adapted to the extremity of a lever attached to the jointed guide that brings the brake into action. So long as the pressure exerted by the movable carbon on the end contact is uniform, the brake does not act,

but the moment this pressure begins to diminish or increase, either on account of nodosities in the carbon, or from other causes, the brake is loosened or tightened, and thus the carbon is allowed to advance more easily or less easily.

This arrangement of the end contact at the extremity of a jointed lever enabled the lamp to be automatically re-lighted in case it went out. For this purpose it was sufficient to place a contact below the jointed lever. When the latter is no longer kept up by the movable carbon, it falls upon the contact spring, and sends the current into the supplementary lamp.

NOTE E.

ON EDISON'S NEW DISCOVERY.

The new metal discovered by Edison, mentioned on page 215, is simply platinum freed *from the bubbles of gas enclosed in its pores by being several times heated in a vacuum for prolonged periods.* Under these conditions the metal becomes much harder than in its ordinary state, and less fusible.

Edison states that he has succeeded in obtaining a wire of this kind, giving with a radiating surface of $\frac{1}{32}$ of an inch, a light of 8 candles, which would, with the ordinary wires of commerce, have been only 1 candle. "I can therefore," he says, "by increasing the calorific capacity of platinum, use wires of very small radiating surface, and considerably reduce the electric energy necessary for the production of a light of 1 candle. *I have, in fact, succeeded in obtaining in this way 8 luminous centres, each giving a perfectly fixed light of 18 candles, and yielding a total light of 138 candles, using for the purpose only 30,000 foot-lbs., that is to say, less than 1 horse-power of steam.*"

TRANSLATOR'S APPENDIX.—No. 1.

ENGLISH EQUIVALENTS OF THE FRENCH DENOMINATIONS USED IN THIS VOLUME.

MEASURES OF LENGTH.

1 kilometre = 1000 metres = 0·6214 *mile*
= 1093·6 *yards*,

1 metre = 1·0936 *yards* = 3·2809 *feet* = 39·37
inches.

1 decimetre = 0·1 metre = 10 centimetres
= 100 millimetres = 3·937 *inches*.

1 centimetre = 0·01 metre = 0·1 decimetre
= 10 millimetres = 0·3937 *inches*.

1 millimetre = 0·001 metre = 0·01 decimetre
= 0·1 centimetre = 0·3937 *inches*.

MEASURES OF SURFACE.

1 square metre = 1·196 *square yards* = 10·7698
square feet.

1 square millimetre = 0·00155 *square inch*.

MEASURES OF VOLUME.

1 litre = 1 cubic decimetre = 1000 cubic
centimetres = 61·02709 *cubic inches* = 0·22017
gallon = 0·88066 *quart* = 1·76133 *pints*.

1 cubic centimetre (cc) = 0·001 litre = 0·06103
cubic inch.

WEIGHTS.

1 kilogramme = 1000 grammes = 2·20462
pounds avoirdupois.

1 gramme = 15·43235 *grains* = 0·035274 *oz.*
avoirdupois.

1 decigramme = 0·1 gramme.

1 centigramme = 0·01 gramme.

1 milligramme = 0·001 gramme.

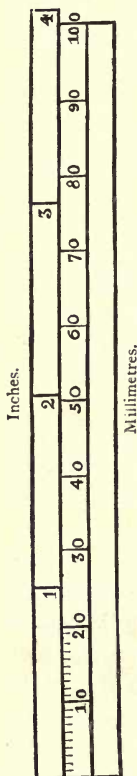


FIG. 75.

WORK.

1 kilogrammetre = 7.233 *foot-lbs.*

THERMOMETRIC SCALES.

To convert centigrade degrees into Fahrenheit degrees multiply by $\frac{9}{5}$ or 1.8, and add 32 to the result.

MONEY.

1 franc = 100 centimes = 9.6 *pence.*

25 francs = £1 *sterling.*

TRANSLATOR'S APPENDIX.—No. 2.

RECENT INVENTIONS.

Since the publication of the original edition of this work, the inventors of electrical apparatus have not been idle. Patents without end have been, and continue to be, granted almost daily for alleged improvements in current generators, and for new forms of electric lamps. But none of these involves any principle which has not been already illustrated in the course of this work, nor does it yet appear that anyone is destined to supersede such forms of apparatus as are described in the text. Nevertheless, there are some quite recent developments of certain forms of apparatus that greatly affect the problem of electric lighting, and these may here be very briefly described.

Incandescent Lamps.—Incandescent lamps of extremely simple construction have been lately brought out by several inventors. These are all identical in principle, consisting of a slender filament of carbon enclosed in a vacuum vessel. They differ in such particulars as the dimensions of the carbon filament, the material from which it is prepared, the method of attaching its extremities to the current con-

ductors, and the manner in which the vacuous vessels are exhausted and sealed. Such lamps will, without damage, bear a certain maximum of current for a more or less prolonged period, the amount of light depending, of course, upon their electrical resistance and the energy of the current. In operation, their average endurance, or "life," has been stated to be, under favourable circumstances, about 1,000 hours. The question of the subdivision of the electric light presents no difficulties with these lamps, and they solve the problem of the application of the light to domestic purposes.

Swan's Lamp.—The inventor of this lamp has discovered a method of preparing from cotton thread very attenuated filaments of carbon of the tenacity requisite for their sufficiently prolonged stability and endurance when in use. These extremely thin carbons are perfectly homogeneous throughout, and are so far from becoming damaged by use that the effect is to a certain extent an increase of their solidity and elasticity. The arrangement of the lamp, which is shown on Fig. 76, is extremely

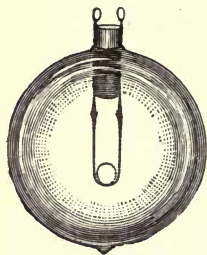


FIG. 76.

simple. The filament of carbon, bent round so as to form a spirally circular loop of about one-fifth of an inch in diameter, is enclosed in a glass bulb about two inches in diameter. The extremities of the filament are connected in an ingenious manner to two platinum wires, which pass outwards and either form two small loops, or terminate in binding screws, for connecting with the circuit. These platinum wires are fused into the bulb, and are supported by a piece of glass, which descends internally for a certain distance. The bulb is hermetically sealed, after having been completely exhausted by means of a Sprengel pump. The light yielded by these lamps is mild and steady, with an intensity depending, of course, on the current of electricity sent.

through them, but which may be safely carried as high as 20 candles. It is stated that 1 horse-power of force absorbed suffices to maintain 10 of these lamps. At the Exhibition of Electrical Apparatus at Paris in 1881, the Swan lamp received the gold medal as being the best system in its class.

Maxim's Lamp.—The carbons for this lamp are prepared from cartridge paper, and the vacuous bulbs contain a residual atmosphere of a hydro-carbon instead of air. It is claimed that by this the durability of the filament is increased, and the irregularities of the resistance at various points become equalized. This form of loop preferred by the inventor has four parallel vertical portions, nearly like a capital M. The resistance of this lamp is stated to be more than twice that of Swan's lamp. The light given out may be carried to 50 candles.

Edison's Lamp and Fox-Lane's Lamp.—Edison prepares his carbon from a filament of bamboo, while Fox-Lane makes use of a string of flax. Both make a single loop of the carbon, which is bent into a horse-shoe form. The resistance of Edison's lamp is about the same as that of Maxim's, while the resistance of the Fox-Lane lamp is less than that of the Swan.

The Faure Secondary Battery.—Planté's polarization battery, which was invented about 1859, has been mentioned in the text (page 15). This battery was formed by the action of the current from a primary battery on plates of lead immersed in diluted sulphuric acid. The nature of the polarizing action itself is explained on page 9. Faure also uses thin plates of lead for the elements of his cell, but instead of forming lead oxide by electrolysis, he coats one of the plates with a film of red oxide of lead, and this is separated from the other plate by a layer of felt. The Faure cells, or "accumulators," as they have been called, are made of a large size, and according to Sir W. Thompson, one of these cells, weighing 75 kilogrammes, "can store and give out

again energy to the extent of an hour's work of one horse-power." The Faure cell may be charged by a voltaic battery or by any generator or dynamo-electric machine giving a direct current. The light of incandescent lamps worked by the Faure accumulator is perfectly steady, being absolutely free from those fluctuations which may usually be detected in the action of the dynamo-electric machines. Its great use for the electric light consists not only in its supplying the means of carrying a store of electricity about, but in affording a *regulator* for the lamps. In fact these might remain lighted for hours, even if the electric supply from the engine were interrupted. A train lighted up with incandescent electric lamps, worked by Faure's accumulators, has been running continuously for some months between London and Brighton, without any failure of the light once occurring. This invention imparts to electric illumination as great a degree of *readiness and certainty in working* as has been claimed for gas-lighting.

THE END.

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